

A PLAIN and FAMILIAR
INTRODUCTION
TO THE
NEWTONIAN
PHILOSOPHY,

In SIX SECTIONS

Illustrated by SIX COPPER PLATES.

Designed for the Use of such

GENTLEMEN and LADIES

As would acquire

A competent Knowledge of this SCIENCE,
without *Mathematical Learning*;

And more especially those who have, or may attend the

AUTHOR'S COURSE

O F

SIX LECTURES and EXPERIMENTS

On these Subjects.

By **BENJAMIN MARTIN.**

Veluti in Speculo.

LONDON:

Printed for W. OWEN at Homer's Head near Temple-Bar.

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INTRODUCTION
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NEW TOWN
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In six sections
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P R E F A C E



THE constant Importunity of my Subscribers, to draw up such an Introduction to Philosophy, as might prepare them to understand the several Subjects of my Lectures and Experiments, and when these are over, to refresh their Memories, and revive, and fix in their Minds, the fleeting Ideas of what they had then heard and seen, is the Reason of the present Publication. I have also taken Care to oblige them in another Respect, and that is

THE PREFACE.

to comprize the whole in so small a Compass, as to put them to a very little Expence, either of Time or Money, to acquire a very considerable Knowledge of all the principal Branches of this most valuable and delightful Science; which by this Means will be render'd of great Service to improve the Mind, and embellish it; but without Assistance of such a Treatise, it cannot be regarded as any Thing more than a polite and rational Amusement.

And not Subscribers only, but any Gentleman or Lady, who is happy enough to have a Taste for Knowledge of the best Sort, will find this small Tract give them as little Trouble in the Pursuit and Acquisition of it, and at the same Time entertain them with as great a Variety and Novelty, as they can possibly expect. When they understand what they here find (for which nothing more than a common Capacity and a little Attention is necessary) they may have Recourse to Books of a higher Class; but, if they have not Mathematical Learning,

THE PREFACE.

Learning, they must be content to understand Philosophy in that Way only which is here taught, viz. By observing the Phenomena of Nature, and deducing from thence their Causes which are render'd general by a just Method of Reasoning, and proved to be by real Experiments. And this is sufficient for Mankind in general.

I shall not here say any Thing to recommend the Study of this Science, having already done that in another Piece*, And that nothing may be wanting to facilitate the Reader's Progress in Philosophical Enquiries, I have embellish'd and illustrated the whole by six Copper Plates, representing the principal Experiments in each of the six Lectures; and also added, a copious Index of all the principal Matters, and accented all the Words for rightly pronouncing them. Also all hard (or technical) Words are thoroughly explained; and, to conclude, I have taken all the Care and Precaution I possibly could, to remove every Thing that might in the least tend to retard the Reader, or render this noble and divine Science less amiable to his View.

* A Panegyric on the Newtonian Philosophy.

The P R E F A C E.

To conclude, I must advertise the Reader that those Propositions, which admit of, or require Mathematical Demonstration, are here put into Italics, and may be found so demonstrated in my Philosophia Britannica lately publish'd. These are all along denoted by an Asterism, thus ()*



C O N.

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A Plain and Familiar
INTRODUCTION
TO THE
NEWTONIAN PHILOSOPHY.

SECTION I.

P H Y S I C S.

Containing a Description of such INSTRUMENTS, PREPARATIONS, and EXPERIMENTS as explain and illustrate the POWERS of ATTRACTION and REPULSION; the PROPERTIES of natural BODIES; the PRINCIPLES of Mechanic Arts; Chemical OPERATIONS; Nature of METEORS; Doctrine of VEGETATION; MAGNETISM, &c.

i.



THE Design of this Course of Philosophy is to exhibit, in a very natural and easy Manner, the principal and most important *Phænomena* or Appearances of natural Bodies; to account for their *Causes* and *Effects* on plain and evident Principles;
B and

and to prove and illustrate the same by a great Variety of curious and new-contrived Instruments and Experiments; so as to render the whole not only the most *rational and instructive*, but also the most *pleasant and satisfactory Entertainment*.

Plate 1.

2. The Subject of the present Lecture, are those *Powers of Nature*, which may be justly esteemed the *fundamental Principles* of all *natural Philosophy*; to shew the Reality of their Existence, their several Properties and wonderful Effects; and to apply the same towards settling a just Theory of *Chemistry*, the *Animal Oeconomy*, *Vegetation*, the Nature of *Meteors*; together with the *principal Properties* of the *Magnet*, and its Use in *Navigation*.

3. This Power affects all the Particles of Matter, and acts upon them in a two-fold Manner, *viz.* 1. By causing them to *accede to, or approach each other*; and because in this Respect they seem to *draw each other mutually*, it is called the *Power of Attraction*. 2. By causing those Particles, in some Circumstances, to *recede, or fly from each other*, it is called *Repulsion*, or a *centrifugal Force*.

Fig. 1.

4. But this Power is in itself *one and the same*, and only acts in this *different Manner* in *different Distances* between the Particles. Thus a Piece of Iron, touch'd with the Magnet, held near one End of a Magnetic Needle will *attract* it; but applied to the
other

other End, it will *repel it*. So the small Particles of Matter being nearly in Contact, strongly *attract* each other, and *cohere together*; but being separated by the Action of Heat, or otherwise, they *repel* and fly from each other, as is evident by many Experiments.

5. Now to shew that the *Repulsion* of one End of the Needle is not a Consequence of Attraction in the other, as some pretend, I *Fig. 2.* take a Needle one half Brass and the other Iron, and the same End is repell'd in this as in the common Needle, which Experiment plainly shews this Repulsion is *real* and *positive* between the two Bodies.

6. And further, it appears by Experiment, that the same End of the Needle, which is *repell'd in one Distance is attracted in another nearer Distance*. And hence it follows, that there is a certain near Distance in which the Particles of Matter attract each other; and which is therefore called the *Sphere of Attraction*; beyond which the said Power acts by *Repulsion*; and so where *Attraction ends there a repulsive Power commences*.

7. This *attracting Power* may be consider'd as affecting immediately the original Particles of Matter, and by that Means causing them to adhere or cohere firmly together, and so qualifying them to form larger Portions of Matter, or Bodies of different Degrees of

A Plain and Familiar Introduction

Consistence, and hence it is usually call'd the *Attraction or Power of Cohesion*.

8. But when we consider this Power in the larger Parts or Portions of Matter, as the aggregate or united Force of all the attracting Forces of the component original Particles, it is then call'd the *Power of Gravitation*, as in the Sun, the Earth, and other planetary Bodies of the mundane System. Because any small Bodies near the Surfaces of those larger ones, are strongly *attracted towards their Centers*; which *Tendency* thereto is in those lesser Bodies called their *Weight or Gravity*.

Fig. 3.

9. This *Power of Cohesion* is directly demonstrated by the Experiment of *two leaden Balls or Bullets*, having their Surfaces made very plain and smooth, and gently press'd together, do cohere so very fast and firmly, as to require the Weight of many Pounds to separate them. Particularly, two of a larger Sort are shewn by the Steel-yard to require not less (sometimes) than two hundred and fifty Pounds Weight to pull them asunder, which shews plainly the prodigious Force by which they adhered together, especially if it be consider'd, that the whole Area of their Contact or Surface, by which they touch'd does not exceed a twentieth Part of a square Inch. Hence no Part of this Cohesive Force can be imputed to the *pressure*

sure of the Air, which will be shewn to be but fifteen Pounds upon a whole square Inch. ()

10. But to reduce to a Calculation this wonderful Power of Nature, by an Experiment, I take a Piece of Brass Wire Part of $\frac{1}{32}$ an Inch in Diameter, and applying it to the Steel-yard, there is required sixty Pounds to pull it asunder; from whence, and the given Area of the Wire, it will be found that the Force of Cohesion in the Surface of a whole Square Inch of such Brass will be at least equal to seventy-six thousand four hundred Pounds, or thirty-five Ton Weight nearly.

11. That this Power acts *only on Contact* of the Particles, or at Distance *indefinitely small*, is evident from many Experiments, particularly those of *Trituration*, or reducing Bodies to *Powder*; for by this Means separating the Particles, they loose their Cohesion instantly; thus all Sorts of Grain are reduced to *fine Flour*; and the hard fix'd Body of Glass is by this means reducible to a *fluid impalpable Powder*.

12. Again, this is further evident by Experiments of a contrary Kind, *viz.* by recompounding and uniting the fractured Parts of Bodies by the Interposition of some Kinds of Matter, which shall fill up the Pores of the Powder, and bind them by this attracting Power into consistent and solid Masses

again. Thus Water unites the Parts of Flour into Dough and Bread ; and the loose dusty Earth into hard *Clods* and *Bricks*.

13. This leads us to consider the Nature of *Cement* in general, which, in every Kind affords most wonderful Instances of this surprising Power. It is well known, that in all hard Bodies, whose Parts cannot be brought to touch each other intimately by Pressure (as in the leaden Balls) the Interposition of some other Body or Matter is necessary to cause an Adhesion between them ; and this interposed Matter, which thus binds the Bodies together, is called a *Cement* ; or in the metallic Kind, *Solder*.

14. Hence it is, that all polish'd Planes, as *Glass*, *Marble*, *Brass*, &c. are made to adhere together, by only wetting their Surfaces with *Water* ; but this Cohesion will be much stronger if *Oil* be used instead of *Water* ; and stronger yet with *Suet* or *Tallow* ; in all these Cases, if the Planes be heated so that the *Oil* or *Tallow* may freely enter the Pores, and thereby more intimately unite with them, the Cohesion will (with *Tallow* be so very great, that in two Planes, whose Surfaces are but *one square Inch*, there is required two hundred Pounds to separate them in very cold Weather, as is shewn by Experiment. So wonderfully great is this Power in less than *half a Grain of Tallow*.

14. The

15. The Nature of *Glues* is from hence evident also; for when those *viscid* Substances are liquified by Heat, they enter the Pores of Wood, &c. and two such Pieces being applied together, and the humid Part of the Glue evaporated, they are by the Remainder attracted, and made to adhere very firmly.

16. Thus, also, if *Isinglass dissolved in Brandy* (which makes the strongest Glue) be poured on the Surface of any Medal, and left to dry on it; there will be formed a most curious *Lamina*, containing the most perfect *Impression of the Medal*; in itself transparent; but may be cover'd with Gold or Silver, as shewn in the Experiment.

17. The Method of *foliating Glass*, proceeds on the same Principle; for Quicksilver pour'd on *Leaf Tin*, will intimately unite therewith, and make a fluid Surface; upon which if a Piece of clean Glass be laid, the Mercury will also enter its Pores, and thus unite or cement the Tin to the Glass, and so convert it into a very useful *Speculum* or *Looking-Glass*, as is shewn by Experiment.

18. In *metalline Bodies*, that are to cohere by *Solder*, it is necessary that the Parts to be solder'd should first be well-cleansed, that when the Metals are heated, and the *Solder* melted, it may in that fluid State, run freely into the Pores on each Surface, and thereby take the more firm hold of them,
and

and when hardened with cold, may bind them with a prodigious Force together. To illustrate this by Experiment, I take a Piece of Braſs well cleans'd, and putting a few Grains of Mercury upon it, rub it all over the Surface with a Piece of Cork, which will thereby become ſilver'd throughout; and two ſuch Pieces put together by their ſilver'd Surfaces will cohere; and could the Quickſilver be in this Caſe fix'd as melted Metals are by Cold, this would prove *a Solder like any of them*; and therefore *fully explain the Rationale of this Proceſs*.

19. By many Experiments it appears there is between different Kinds of Bodies, a different Power of Attraction between their conſtituent Particles. Thus when *Water is put into a Glaſs*, it is ſeen to riſe all round by the Side, which it could not do if the Particles of the Water were not attracted more by the Glaſs than by each other. For 'tis eaſy to underſtand if the Particles of Water next the Glaſs, were attracted on each Side, or every Way equally, *they could not move at all*, much leſs could *they riſe upwards*, contrary to their own *natural Tendency or Gravity*.

20. On the other Hand, if *Mercury* be put into a Glaſs the Surface of it is lower all round by the Sides than in the Middle, which ſhews that the Parts of Mercury are more attracted by themſelves than by the Glaſs, becauſe, were they equally attracted by

by the Glass, they would be on every Side equally attracted, and consequently the Surface would be every where even or plane.

21. On this Principle 'tis easy to account for the rising of Fluids in *Glass Tubes* with small Bores, called *Capillary Tubes*. For since the Water within the Tube is solicited upwards by a superior Attraction (*Art. 19.*) it will rise in the Bore so far till the Weight of the Cylinder thus raised *is equal to the Excess of the attracting Force*, and then there it will stand continually. This is all evident by Experiment.

22. Since this Power *acts only upon Contact*, (*Art. 11.*) the Water can be affected only by those Particles of the Glass that are contiguous to them above the Surface, and therefore *only by a Circle of Particles* equal to the Circumference of the Bore of the Tube; and therefore since all Effects are proportional to their Causes, the *Quantities of Water raised in Tubes of different Bores must necessarily be in Proportion to the Circumferences, or to the Diameters of those Tubes*.

23. Hence if the Diameters of the Bores *Fig. 4.* of two Tubes, A and B, be as 2 to 1, the Quantity of Water raised in A, will be twice as great as that raised in the Tube B; but the Height of that in B, will be double the Height of the Fluid in A; because the Quantity of the Fluid in A, is to that in B, of

of the same Height as four to one (* being as the Squares of their Diameters) therefore half the Quantity in the Tube B, must have double the Height of that in A ; and hence universally, *the Heights to which Fluids will rise in capillary Tubes, will be always greater in proportion, as the Diameters of the Tubes are less.*

24. And as the Water rises in these Tubes, so Mercury will stand in them below the common Level of that without ; and these Deficiencies will be greater, as the Diameters of the Tubes are smaller, for the Reasons before mentioned (in *Art. 20.*) which is also evident by Experiment.

25. From hence also we see the Reason why all Fluids rise so readily into Sponge, Sugar, Sand, &c. to very great Heights ; because there is a much greater Force of Attraction between the Particles of these Bodies, and those of the Fluids, than there is between the Parts of the Fluids themselves.

Fig. 7.

26. Hence also we have the Reason of the Operation of the capillary Siphon C D, which raises Water thro' one Part by Attraction, and carries it over the bended Part, into the descending longer Leg, where it descends by its Weight and drops out.

Fig. 7.

27. This accounts for the Nature and Action of the Filtre A B, the most simple of all the chemical Instruments. For as this is made by small Pieces of Linnen or Woolen Cloth,

Cloth, Yarn, Thread, &c. the several Filaments attract the Fluid in the same Manner as the *capillary Siphon*, and carry off the Fluid *Drop by Drop*.

28. And indeed *all the more considerable Operations of Chemistry* are explicable upon this most simple Principle. Thus in the *Solution of Bodies* in various Fluids or *Menstruums*, nothing is required more than a greater attracting Force between the Particles of the Fluid and the Solid, than there is between the Particles of the Solid themselves; and therefore, when the solid Body is immersed in the Fluid Menstruum, those Parts which are in immediate Contact with the Fluid, must necessarily lose their own Cohesion, and be separately attach'd to the Particles of the Fluid; and since this will be the Case continually, till every Particle of the *Menstruum* has attracted and united to itself so many of the Solid as it can sustain, the Solid will by this Means continue to be dissolved for some Time, *viz.* till the whole Medium is saturated therewith, and then the Solution ceases. All which is manifest by Experiments of any *metalline Bodies, Mercury, Chalk, &c.* put into *Aqua fortis, Spirit of Nitre, Vinegar, &c.* Fig. 5.

29. In Solutions of this Kind, several Things offer themselves very well deserving our Notice. As *that most, if not all, hard and fix'd Bodies are by this Means reducible*
to

to a State of Fluidity. That the heaviest Bodies, as Gold, Mercury, &c. are hereby suspended in Fluids many Times lighter than themselves. That the most opake Bodies, as Mercury, &c. may, by having their Parts thus attenuated, be render'd most transparent and pellucid, &c. &c. &c.

30. In this Process of Nature we may observe, the Action between the Fluid and solid Body is much more intense and violent in some Cases than in others, thus *Aqua fortis* attracts the Particles of *Brass*, much more strongly than those of *Lead* or *Tin*; and the Parts of *Iron*, with much greater Violence than those of *Brass*; and in Proportion as this intestine Action of the Parts is greater, there will be produced a greater Degree of *Heat* in the Solution, attended with a strong *Ebullition*; and upon a Mixture of some *essential Oils*, this Commotion of the Parts will be so sudden and violent, as instantly to cause a *real Accension*, or pure Flame to rise, which fully confirms Sir *I. Newton's* Doctrine, that *all Degrees of Warmth, Heat, Fire, and Flame are solely produced by various Degrees of the intestine violent Motion of the Parts of Bodies.*

31. If the *Menstruum* be placed in a Sand-Heat, its Action will be render'd much stronger, and it will dissolve much more of the Metal; and then if it be taken off, and set by to cool, it will as it grows colder, have its attracting Power lessen'd, and will
let

let go a Part of the dissolved Metal, which, as it precipitates, will be seen to form *thin crystal Flakes*, and fall in the *Form of Snow* to the Bottom; as will be very evident in such a *Solution of Silver*.

32. In general if *Water, Salt, or some* Fig. 6. *other Body* be put into a metalline Solution, it will be thereby weakened, and the metallic Parts being thus mingled and entangled, can be no longer suspended, but will fall to the Bottom in form of a fine impalpable Powder; which when the Fluid is poured off, and is dry, becomes a proper Subject for *silvering*.

33. Thus such a Powder obtained from a Solution of *silver*, is made use of by various Artificers for *silvering of Brass, Copper, &c.* And thus a *Gold Powder* may be obtained by a Solution of that Metal in *Aqua-Regia*, or *Aqua-Fortis* in which *Salt* had been dissolved. In order to perform this Operation with Success, the Parts of the Metal to be silver'd, must be well cleansed, and the Powder mixed with Salt of Tartar, and rub'd on with a Cork dip'd in Water, after which it must be polish'd and varnish'd. (See *Art. 18.*)

34. These are some of the many Instances that might be produced to shew how entirely most of the Operations of CHEMISTRY depend on this Principle of Attraction, and can be accounted for most naturally by it. But many Processes of *natural and artificial Chemistry*, are found to result from that other
Part

Part of this wonderful Power which acts by *Repulsion*: For as it was necessary that the Particles of Matter should, in some Cases, *attract and adhere to each other*; so, in other Cases, it is as necessary they should *repel and fly from each other*; that they may by this Means be qualified to produce all the different Kinds of *elastic Bodies*, and their various and surprising Effects in all the Scenes of Nature,

35. Thus the AIR is produced by the *Action of Heat* (proceeding from the *Particles of Light*) in all Bodies which separate their Parts (on the Surface) *beyond each others Sphere of Attraction*; and which then begin to repel each other, and so an imperceptible *Effluvium* of aerial Particles is generated from all Bodies, having a *centrifugal Force* between them, in which the *Springiness* or *Elasticity* of the Air does wholly consist; but of this I shall say more in the *Pneumatic Lecture*, and illustrate this Operation by Experiment.

Fig. 8.

36. Also by the Action of Heat, (from the *Fire, Sun, &c.*) the Particles of Water being on the Surface separated, immediately repel each other with a Force somewhat greater than that in Air; whence these aqueous Particles will have larger Interstices, and must therefore be *less dense than Air*, and so have a *less specific Gravity*: These aqueous Particles therefore must rise from humid Bodies

Bodies into the Air in the Form of *Vapour*, till they arrive to that Part of the Air whose specific Gravity is the same with their own; and there they will float about in those large Collections we usually call *Clouds*.

37. As the Gravity of the Air is greater or lesser, the Clouds will be higher or lower; and when the Air suddenly becomes lighter, the *Clouds or Vapours* are precipitated; and in their hasty Descent, are condensed, and coalescing into larger Portions, are render'd heavier than the Air, and of course fall thro' it in *Drops*, and thereby make *Showers of Rain*.

38. There is always a requisite Degree of Heat in many Bodies to keep them in a fluid State; and the Cause of this Warmth or Heat (*viz.* the intestine Motion of the Parts, See *Art.* 30.) being subject to a Diminution by the Mixture of some Sorts of Matter, particularly Salt, it happens that when the *Nitrous Salts* (which have this Power in the greatest Degree) are copiously mix'd with these Vapours in the Air, they lose their *Fluidity*, and become congeal'd into *Sleet, Snow, Hail, &c.* according to its lesser or greater Proportion in the Mixture.

39. The Earth affords also a large Exhalation of *Sulphur*, which when it becomes mix'd with the Nitre of the Air, and mineral Particles, which are copiously sublimed from Mines and metallic Bodies, there will ensue a Fermentation, which when it is sufficiently

ficiently excited, will produce an *Accension* or *Flame*, and make what we call *Lightening*. In this Case the Spirit of the Nitre is greatly rarefied, and if entangled and confin'd in the Body of the Cloud, expands itself with such great Violence and Impetuosity, as to make that *prodigious Explosion* we call *Thunder*. All which is very evident by the common Experiment of *firing Gunpowder*.

40. From hence also we see the Reason of those chemical Processes we call *Distillation*, *Sublimation*, &c. which are nothing more than a *Fluid* or *Solid Body*, having its Parts by the Action of Fire separated beyond their Sphere of Attraction, and by that Means put into a *repelling State*, in which they rise from the Subject in the Form of a *Steam*, and are by the Recipient condensed again into a *Liquor*, or collected into a Body of fine *impalpable Powder*, call'd *Flowers*, *Sublimate*, &c.

Fig. 9.

41. From what has been premised, we may easily deduce the Cause or Reason of all the various Degrees of *Hardness* and *Softness*, *Fixity* and *Fluidity* in natural Bodies. For since this Power is proportional to the Quantity of Matter, and acts in those Particles only that are in contact, or nearly so, it follows that the greater the Number of Particles or Quantity of touching Surfaces is, the greater will be the Cohesion; and therefore those Particles whose Surfaces are large and plane, and their

their Figure such as will admit of the greatest Congruity, or Quantity of Contact, must necessarily constitute the most hard and consistent Bodies.

42. But if the Figure of the Particles are *Fig. 10.* very irregular, by which Means they touch partly by their plain Surfaces, and partly by their angular Points, or in some such like Manner, then the Degree of Cohesion between them must be less, and they will be liable to be moved among themselves, and will therefore constitute the more soft and yielding Substances or Bodies.

43. Lastly ; If the constituent Particles *Fig. 11.* be of a spherical Figure, * they will touch each other in single Points only ; the Cohesion therefore between them will be the least possible ; and they will be put into Motion with the least Force, and so constitute the most voluble or Fluid Body.

44. We now proceed to account for the *Fig. 12.* Nature, and establish the Theory of Vegetation in all Kinds of Plants ; and here we find, by examining their Structure with proper Glasses, that the lignous Substance of Plants and Trees, is nothing more than a Congeries or Assemblage of an infinite Number of capillary Tubes, all connected or bound together by transverse Ligaments or Bands. These are shewn in a Preparation as here represented in the Figure.

C

45. If

Fig. 13.

45. If either the Root or Stem of a Plant be cut transversely with a very sharp Knife, the Orifices of these Vessels, or *vegetable Tubes* will appear innumerable over all the Surface; and if an extreme thin Slice be taken off, and held up against the Light, it will appear almost transparent, by Reason of such a Multiplicity of Holes or Pores, somewhat like what you see in the Figure.

46. The Vessels or Tubes appear, in the Solar Microscope, to be of two Sorts, *viz.* one, which are large, destined for the Passage or Circulation of *Air* thro' the Body of the Plant, and are therefore called *Air-Vessels*; and these are they which appear so plainly and numerous to the naked Eye in those Pieces of the *Convolvulus* (or *Bithwind*) which I shall shew in the Section.

47. For as to the *second Sort*, they are so exceeding small as not to be distinctly seen with the Eye alone, nor sufficiently magnified by any other Instrument than the *Solar Microscope*. These are fitted on this Account to attract the Moisture or nutritious Juices of the Earth, by means of the Roots thro' which they are continued in innumerable and *minute Ramifications*.

Fig. 14.

48. That the larger Vessels contain and circulate the Air is beyond Dispute made evident by many curious Experiments on the Air-Pump; and that the smaller Sort have an *attracting Power*, (the same as the aforementioned

mention'd Capillary Tubes in Glafs, *Art. 21.*) For by a new Experiment we shew a *vegetable Siphon*, A B attracts and draws the Water out of the Glafs in the same Manner as the *Glass capillary Siphon* did, (*Art. 26.*) And this affords an *ocular Demonstration* of the Force there is in Plants to draw up their nutritious Juices from the Earth. And as the Heights to which it must rise in Trees is very great, it was necessary that the Vessels should be exceeding small for that Purpose, as is evident from *Art. 23.*

49. That the *Sap* rises, by means of these *Fig. 15.* Tubes, thro' all the Body of the Tree (and not between the Bark and the Wood as is usually supposed) seems evident from the following Experiment, A F is a part of a Bough with the Bark taken off all round in two Places B C and D E, and from the intermediate Part C D there grows a Twig G, whose Leaves will grow and flourish all the Season of Vegetation, as well to appearance as any of the rest on the Tree; as will also all the Leaves on the Twigs beyond the Part A. From whence it follows, that all the Nourishment to these Leaves must be derived from the Sap which is carried to them by the Tubes, which go off from the Body of the Bough thro' the Stem of the Twig G, since the Wood where the Decortications are made, are perfectly dry all the Time.

50. Again it appears by this Experiment, that after the Tree is supplied by this means with Sap for *Vegetation*, and the Leaves have attain'd their *full Growth*, that part of the Sap returns from the extreme Parts between the Bark and the Wood, because we see the upper Parts of the Incisions of the Bark at B and D become swollen, protuberant and callous to a great Degree; whereas the lower Parts at C and E shrink in, and look dead; which plainly argues the Sap is obstructed in its Return or Descent at B and D, and there lodging swells out the Lips of the Incision, while none coming to the Parts C, E, they become emaciated and wither'd.

51. Again, this *returning Sap* seems necessary for the Support of the Leaves after they have arrived to their full Growth, for tho' the Leaves on the Twig G vegetate and grow equally with the rest, yet they decline, sicken, grow pallid, and die away some time before the rest on the other Parts of the same Bough and Tree. And even those on the Bough, beyond the Decortication B C, will not continue their Verdure and healthful State so long as the other Leaves of the Tree.

Fig. 16.

52. But to put this Matter beyond all Doubt, I tried the following Experiment. I separated with a Knife the two Twigs C and E from the Body of a Bough A G, and kept them so by a small Wedge under each; then

then at B, just above and over the part D I, cut away the Bark to prevent any Sap from returning to the Twig C from above, and as none could come to it from the Body of the Bough being separated from it,) the Consequence was, that the Twig and its Leaves immediately died and wither'd away; whereas those on the Twig E being supplied with the descending Sap, continued their Verdure equally with the rest on the Tree till the Fall.

53. These vegetable Ducts or Tubes we have been speaking of, and of which the lignous Part of the Plant is made, are detached from the Boughs in small Portions thro' the Foot-Stalk, or Tail of the Leaf, under proper Integuments, to be distributed thro' all the Body of the Leaf, where they perspire, or throw off all the superfluous Part of the Sap. These *tubular Fibres* as they are contain'd in the Tail of the Leaf, prepared, dissolved, and expanded, you see represented in *Fig. 17*.

54. The beautiful and wondrously fine Ramifications of these Vessels thro' the Leaf itself you see in *Fig. 18* and *19*, where you observe moreover, that each Leaf is a Du-*Fig. 18.*
plicate of these Vessels, or consists of *two* *Fig. 19.*
Systems or Layers of Fibres; one of which is very fine, as *Fig. 18*; and the other much coarser (*Fig. 19*.) These answer to the *System* of Arteries and Veins in an animal
C 3 Body.

Body. And into these two Parts, many Leaves (as those of *Holly*, *Apple-Trees*, &c.) do naturally resolve themselves in their Preparation in Water, of which the two present Figures are an Instance.

55. I shall only further observe, that this extreme Ramification of the Vessels in a Plant is every way analogous, or alike to that in Animal *Arteries and Veins*, as I shew by a Specimen of these *latter injected*, compared with the *Leaves anatomized*. There is also a further Similitude in the *Contexture of these organized Bodies*, which I also illustrate by *proper Specimens and Preparations in each*.

56. Indeed there is this Difference in the Oeconomy of Nature in animal and vegetable Bodies; that in the former, she makes use of the *muscular Force of the Heart for the Pulsion, Protrusion, and Circulation of the Fluids and Juices* by which the Body is nourished; whereas this in the latter is effected *principally by the capillary Attraction*, in the Manner as above explain'd.

57. In the last Place with respect to Plants I shew by *Preparations of Bark and Wood*, that the Plant or Tree does each Year increase by the *Addition of a lignous cylindric Shell*, which firmly adheres to the former, and which is yearly derived from the *interior Bark*, which contains them in almost infinitely thin *Laminæ*; one of which from Year to Year has its Vessels expanded by the Sap,

Sap, and grows by degrees into a thick woody Substance, consisting of *Sap and air Vessels*; and by a Kind of *vegetable Articulation*, it is naturally fitted into, and unites with that of the preceding Year.

58. Having thus sufficiently illustrated the Nature and Use of this *universal Power of Attraction and Repulsion*; I shall in the next Place, just give an Instance of the Nature and Use of another Power of *Attraction and Repulsion*, which is *of as singular a Kind*; as it is form'd to affect only two Sorts of Matter, *viz.* the *Load-stone* and *Iron*; but it possesses the former in a most eminent Degree.

59. This Virtue is emitted from two Parts of the Stone or Magnet in a very fine imperceptible Effluvium; and if Pieces of Iron be properly placed over those two Parts, it will be as it were attracted, accumulated and condensed in the Iron, and from thence will be emitted or communicated with much greater Force and Intensity than from the Stone itself.

60. The Criterions or Marks of a good Magnet, are *Blackness*, *Hardness*, and *Heaviness*. It attracts and repels Iron, but touches no other Sort of Matter; the same End of a suspended Needle which is attracted by one end of the Stone, is repell'd by the other. It may be communicated from the Stone to Iron, which if form'd into a Needle, and suspended on a fine Point, will turn into a

Position towards the *North and South*, and there it will stand at Rest.

Fig. 20.

61. The Angle ACN which the magnetic Needle AB makes with the meridian Line NS is call'd the *Variation of the Needle*; and this being the same in any one Place for a long Time, or known by Observation for any particular Place and Time, renders it of the greatest Service in Navigation: Because it gives you the Angle ACF which the Ship's Course DF makes with the Needle AB ; and therefore the Angle NCF , which it makes with the Meridian NS ; whence by allowing for Lee-Way, they are able with great Certainty and Exactness to compute every Thing relating to the *Departure, Difference of Longitude, Difference of Latitude, Distance sail'd, &c.*

62. The magnetic Needle is also very useful in conducting Travellers thro' unknown Countries and Roads by Land; by presenting to their View at all Times the Bearing or Point of the Compass on which the Place they are going to lies. It is likewise very useful to shew the Hour of the Day whenever the Sun shines, in those call'd *Compass Dials*. Also by knowing the Hour of the Day, you find the true Declination of the Needle for any Place. All which, and many other Particulars are illustrated and exemplified in the Lecture, by *Magnets both natural and artificial.*

63. If a few Steel-filings be sifted finely *Fig. 21.* over a Sheet of fine Paper, and the Magnet placed in the Midst of them; it will be very pleasant to observe how all the Steel Particles are affected with the Virtue issuing from each Pole of the Stone, by which they are moved into Curve-lined Directions, and circular Positions between the Poles, very much like what you see represented in *Fig. 21.* From whence we learn that there is a Kind of Circulation of this Virtue from one Pole or Part of the Stone to another. Dr. *Halley* supposes, with a great deal of Reason, that there is a large central Magnet in the Body of the Earth; and that it is moveable in the Earth like the Kernel of a Nut in the Shell, which by that Means causes all the *Variety of the Declination* of the Needle, and also its *dipping below the Horizon of a* *Fig. 4.* *Place.* He also supposes the external Shell of the Earth to be magnetical; and which not having a similar Motion and Position with the *Nucleus*, or internal Magnet, occasions all the Irregularity in the Variations of Motion of the Needle.

SECTION



SECTION II.

The Nature of LIGHT explain'd; the Laws of REFLECTION and REFRACTION of LIGHT; the Nature and Effects of MIRRORS and LENSES; the Prismatic COLOURS of Light; the Nature of VISION by a Natural and Artificial EYE; of the common MICROSCOPE; the SOLAR MICROSCOPE; of Refracting and Reflecting TELESCOPES; of Camera Experiments and Instruments.

I. **T**HE Subject of this Section is the Doctrine of *Light, Colours, Vision* and *optical Instruments*.

2. LIGHT consists of the most subtile or smallest Parts of Matter; and is appointed by Nature the *material Cause* of *Vision* or *Sight*. Its *luminous Quality* depends upon the Minuteness of the Parts, and the great Velocity of their Motion. For as the Particles of Light are the smallest of all others, so they move with the greatest Swiftmess; * for by Experiment, it has been found that
it

it moves at the Rate of *Ten Millions of Miles in a Minute.*

3. This Kind of lucific Matter was at first all collected into a Body of an enormous Size, to serve as a Magazine or general Receptacle of Light; this we call the SUN, from which the Light is constantly dispensed thro' every Part of the System, to answer all the Purposes of *Light, Vision, natural Heat, Vegetation, &c.* in the several planetary Worlds.

4. These Particles of Light emitted from the Sun, and falling upon the Surface of Bodies, is in Part reflected from the Surface, and in Part imbibed into or refracted thro' the Substance of the Body. Thus let A B ^{Fig. 1.} be the Surface of a plain Mirrour, D C the Ray of Light falling thereon at C, and let C E be perpendicular to the said Surface; then will the Ray D C be so reflected into the Ray C F, as to make the Angle of Incidence D C E equal to the Angle of Reflection E C F, as is very evident by Experiment in the *Camera Obscura.*

5. That Part of the Beam, which enters the Substance of Bodies, puts their Parts into Motion, and according as it is imbibed and detain'd in a greater or lesser Degree, it actuates the parts of those Bodies more or less, and produces in them such Degrees of Motion, which, when it affects our *nervous System*, excites in our Minds the *Ideas of Warmth, Heat, &c.* by those of *Feeling*; and

and of *Light, Flame, Colours, &c.* by those appointed for *Vision*.

6. When the Parts of Bodies and also their Pores are so large as to cause such irregular Reflections, and Refractions of the Light thro' the Substance, that it cannot go on, or be transmitted thro' it in right-lined Directions, it is evident we can see none of the internal Parts of that Body, which is therefore said to be *opaque*. As on the other Hand, that Body is *transparent*, which transmits the Light so regularly through its Substance to the Eye, that all its internal Parts are thereby render'd visible.

Fig. 2.

7. In these Sorts of Bodies we determine the *Law of Refraction* by Experiments in many different ways; one of which, as it is very easy, I shall here explain. Let A B C D be a Vessel, set in the dark Room, where the Beam of the Sun E F shall just touch the Top of the Side A D, and pass on to the Point F at the Bottom. Then filling the Vessel with *Water* to the Brim, the Ray of Light E A will not now go thro' the *Water* to F as before, but will be bent into the Direction A G, which is therefore call'd the *refracted Ray*, and the Angle D A G is the *Angle of Refraction*; as D A F is that of *Incidence*.

8. If on the Side A D we describe with the Radius A D the Arch of a Circle D M, and from the Points H and K where it intersects

fects the refracted and incident Rays, the Lines H I, K L, be drawn perpendicular to A D, these are call'd the Sines of the Angles D A G and D A F; and are always to each other in the Proportion of 3 or 4 nearly in *Water*, as 2 to 3 in *Glass*; and as 2 to 5 in *Diamond*. Whence it appears, that the greater the *Density* of the refracting Medium, the greater will be its *refractive Power*, tho' not exactly in the same Proportion; but here we must except *Oils and spirituous Liquors*.

9. We shall now apply the Doctrine of *reflected Light* to account for the Effect of *concave and convex Mirrours*. Let A B be a Segment of a hollow Globe of Glass, whose Center is C; and Quicksilver'd on the convex Part A B. The Ray or right Line H V, that passes thro' the Center C and falls on the middle Point or *Vertex* V of the Mirrour, is call'd the *Axis* of the Mirrour; let D G be another Ray from the Sun parallel thereto, and thro' the Point of Incidence G draw C E, * this will be perpendicular to the Mirrour in G, then make the Angle C G F equal to the Angle C G D, and G F will be the *reflected Ray*; and the Point F will be in the middle between C and V, and is call'd the *Solar Focus*, because all the Sun's Rays will be there collected into a small bright Spot, and burn very intensely; all this is evident from the Law of Reflection in *Art. 4.* Fig. 3.

10. Suppose any *radiant or luminous Body* were placed near the *Mirroure* in the *Axis* at (*d*) and let *d G* be a Ray of Light passing from it to the *Mirroure* in *G*; then make the Angle *C G f* equal to the Angle *C G d*, and *G f* will be the reflected Ray, and the Point *f* will be nearer the Center *C* than the Point *F*. If the Point *d* coincides with the Point *C*, then the Ray will be reflected upon itself. If the Radiant be at *f*, and *f G* the incident Ray, then *G d* will be the reflected Ray. If the Radiant be placed in the Focus *F*, the Ray *F G* will be reflected into *G D* parallel to the *Axis*. And lastly, if it be placed nearer the *Mirroure* as at *K*, the reflected Ray *K G* will be *G I*, proceeding from the *Mirroure* as if it came from the Point *M* in the *Axis* of the *Mirroure* behind it. All this is evident likewise from the same Principle in *Art. 4*.

Fig. 4.

11. Hence we may easily infer every Thing relating to the *Formation of the Images of Objects* in a concave *Mirroure*; for let *A B* be such a *Mirroure*, and *O B* an Object placed beyond its Center *C*, then since the *Axis C V* is perpendicular thereto in the Vertex *V*, the Particle of Light coming from the Point *O*, of the Object in the Direction of the *Axis*, will be reflected back in the same Direction to its Focus at *I*, where that Point *O* will be represented. Then from the other extreme Point *B* let a Ray proceed to *V*,
and

and making the Angle $I V M$ equal to $B V O$, we have $V M$ the reflected Ray, and the Point M will be the Representation of the Point B . And hence all the Rays proceeding from every Part between O and B will be reflected to the Line $I M$, and so the whole Line $I M$ will be the Representation or Image of the Object $O B$.

12. Hence it appears that the *Position of the Image*, with Respect to that of the Object, must necessarily be *inverted*, and on the contrary Side of the Axis. Hence also it appears, since the Object and Image are both seen from the Vertex of the Mirrour under equal Angles $B V O$, and $I V M$, * *the Length of the Object will be to that of the Image as the Distance of the Object $O V$ to the Distance of the Image $I V$ from the Mirrour.*

13. Therefore, while the Object is farther from the Glass than the Center C the Image will be on *the same Side*, but *nearer to it*, and *less than the Object*. If the Object were placed in the Center C , the Image would be there form'd also, in an inverted Position and *equal* to the Object: If the Object be placed between the Center C and Focus F , as at $I M$, then will $O B$ be the Image form'd beyond the Center, *inverted* and *magnified*. If the Object be placed in the Focus F , the Rays will be all reflected parallel to the Axis, and form the Image at an *infinite Distance*, and infinitely large. Lastly,
suppose

Fig. 3.

suppose the Object placed any where between the Focus F and the Vertex V, as at K, the Image will be form'd behind the Glass at M, in the *same Position* as the Object, and *magnified*. These are the *principal Properties of concave Mirrors*, which are all of them demonstrated by Experiments.

14. In the same Manner I might shew, that Rays of Light falling on a *convex Mirror*, and reflected by the same Law (*Art. 4.* will all proceed diverging from the Glass in such Manner as if they came from a Point behind it ; so that these Glasses have no real *Focus* or burning Point ; they form the Image *only behind, always erect, and less than the Object* ; so that no magnifying Power belongs to this Glass, when used singly by itself. These Things appear also by Experiments with those Glasses.

Fig. 4.

15. If the Rays of Light pass thro' a Glass whose Surfaces are plain they cannot be refracted towards one Point, or Focus ; but if one or both the Surfaces are convex, they will be so refracted, as may be thus easily shewn : Let A B D be such a *convex Glass* or *Lens* ; C K its Axis, and let the convex Surface A B be described with the Radius M E, and the Surface A D, with the Radius C O, and let F E, a Ray of Light parallel to the Axis, fall on the Lens at E, which as it there meets with the *dense Medium* of Glass will be refracted out of its parallel Direction
E N

EN into another EK, so as to make the Sine of the Angle of Incidence MEN, to the Sine of the Angle of Refraction KEN, as 3 to 2; (as is evident from *Art.* 7, and 8.) The Ray FE therefore will by the first Refraction tend to a Point K in the Axis.

16. But as the Ray, passing thro' the Glass from E to O, there meets with another *convex Surface*, where it must now be refracted into a *rarer Medium*, or Body of *Air*; therefore the Ray EK will now be refracted into another OL, so as to make the Sine of the Angle of Incidence POK to that of the Angle of Refraction POL as 2 to 3. The Ray FE therefore after Refraction at both Surfaces, will meet the Axis at the Point L.

17. If the two Surfaces AB, AD, be equally convex, or the Radius CO be equal to ME, then will the Point L coincide with M; or *parallel Rays*, by means of such a Glass, will be converged to a *Focus*, at the Distance of the *Radius of Convexity*. Thus the parallel Rays ABCD falling on a *double and equally convex Lens* will be all converged to the Focus F, where they all cross each other; and from thence go diverging towards G and H. Fig. 6;

18. Let AH be the Axis of a Lens DE; Fig. 7. than if O be any luminous Point in the said Axis, the Rays which proceed from them to the Lens DE will all be refracted or converged

D
verged

Fig 7.

verged to a Focus in the Point I on the other Side. And if O B be an Object then all the Rays proceeding from the other Extremity B to the Lens will be refracted to the Point M in the right Line B M, passing thro' the Center of the Lens C. Therefore all the Rays from every Point between O and B in the Object will be collected respectively into so many Points between I and M, and thereby constitute the Image I M of the Object O B, in an *inverted Position*.

19. Because only parallel Rays can be converged so near the Lens as its Focus F (by Art. 17) therefore Objects only at an *infinite* or a *very great Distance* can have their Images form'd in or very near the Focus of such a Lens. If the Object O B approach towards the Lens, the Image I M will recede from it, and become bigger and bigger, till the Object arrives to the Point which is double the focal Distance from the Lens, and there the Image will be also at the same Distance on the other Side, and equal to the Object. As the Object O B proceeds from hence towards the Lens the Image I M will recede farther, and become bigger than the Object; till the Object arrive at the Focus of the Lens, and then the Image, being form'd by *parallel Rays*, must be at an infinite Distance and infinitely large. Lastly, if the Object be nearer the Lens than the Focus, the Image will become *negative*, or form'd on the same Side

Side with the Object, and always bigger than the Object, and in an erect Position.

20. These are Properties of a *convex Lens*.

As for *concave ones*, they are quite the reverse; thus if the *parallel Rays* A B C D fall on a concave Mirrour, they will be refracted *Fig. 8.* into a *diverging State* toward G and H, in such Manner as if they came from a *Focus* F on the other Side. If the Mirrour be a *Plano-concave*, this Point F, or *virtual Focus* will be at the *Distance of the whole Diameter of the Sphere of Concavity*. If it be double and equally Concave, the Point F will be in the *Center of Concavity*.

21. If *converging Rays* G H tend to a Point F, and a *Concave* B C be so placed to intercept them, that its *virtual Focus* shall coincide with the Point F, then will those Rays after Refraction go *parallel from the Lens*, as represented in the Figure.

22. Having thus accounted for the Nature and Laws of Refraction, it will now be easy to account for the *Colours of Bodies* by Experiments of the *Prism*. For let A B be a Prism *Fig. 9:* and C D a Beam of Light falling upon it in the Point D; it will pass thro' and be refracted on the other Side at E in such Manner that the refracted Ray R E shall make an Angle with the Perpendicular E F greater than the Angle H E F, which the Incident Ray C H makes with it, by the Law of Refraction (*Art. 7.*)

23. But then we shall observe that the Rays of this Beam will not equally refracted, but some Part will go to R, another Part will be more refracted, and go to O; another Part to I, another to G; other Parts to B and I; and that which is most of all refracted to V.

24. Now since the *refracting Power of the Prism* is every where the same, if the Rays or Particles of Light were all of the same Size or Magnitude, they must necessarily be all equally or alike refracted, *viz.* to one and the same Place. But as this is not the Case, it evidently follows, that these luminous Particles are of *various different Magnitudes*; and that those which are largest, and, of Course, least Subject to the refracting Power, will be *least of all refracted*, and therefore fall nearest the Perpendicular, *viz.* in the Direction E R. As on the other Hand those which are of the *least Size*, must needs be *most refracted*, and will go from E to V; and all the intermediate Rays according to their several Magnitudes, will fall between R and V.

25. And here we are next to observe, that as *Nature has caused the Idea of Vision in general to arise from the Action of a Particle of Light upon the optic Nerve in the Eye*, so this Idea of the *Form* is always connected with another which we call COLOUR, and which arises from the peculiar and different Action

or

or Force with which each particular Ray affects the Nerve. Thus the Rays E R being largest strike with the greatest Force, and by that excite the Idea of *Redness* in the Object which emits it. Again, those which are least of all, and strike the Nerve with the least Force as the Rays E V, make the Idea of a *Violet Colour*; and the Rays at O make an *Orange Colour*; at Y a *Yellow*; at G a *Green*; at B a *Blue*; and at I an *Indigo Colour*. All which Particulars appear extremely plain and beautifully by the Prism in a dark Room.

26. Hence, since we find by common Experience, that there is in different Parts of Matter a *different Power of Attraction and Repulsion* (Sect. I. Art. 2.) that is, in this Case, of *Refraction and Reflection of Light*; it must follow, that those Bodies whose Particles have a Power of reflecting or refracting any one Sort of Rays alone, or more copiously than the Rest, must necessarily appear of that particular Colour, which is caused by those Rays. Thus *Vermillion* throws up all the red-making Rays, and imbibes the Rest, and must therefore appear *red*. Gold reflects all the yellow-making Rays, and so must appear *Yellow*; and the same may be said of all the Rest.

27. If, as in some Cases it happens, a Body reflects one Sort of Rays, and transmits another, it must necessarily appear of one Colour by Reflection, and of another by Re-

fraction. Thus Leaf-gold appears *Yellow* by *reflected Light*, but of a fine *Azure* or *Blue-green* by *refracted Light*. Also a *Tincture* of *Lignum Nephriticum* appears of a deep *Blue* by *reflected Light*, but *Red* by *the Light refracted thro' it*. All which is confirm'd by Experiment.

28. The Rays of Light are not only *separated by Refraction* but also by *Reflection*; and hence in some Kinds of Bodies where the Power of Reflection is uniform, the Rays of Light must, according to their several Magnitudes, be reflected under different Angles; whence the Eye placed in one Position sees the Object of one Colour, in another Position of another Colour; and thus by moving the Eye or Object, the same Part shall appear of different Colours successively, as is evidently shewn in a *Peacock's Feather*, the *Wings of small Flies*, *thin Bubbles of Soap Water*, *Silks*, *Satins*, &c.

29. Those Bodies which reflect all the Rays of Light as they fall, must necessarily appear of the same Colour with the Sun's Light, *viz. White*, and such Bodies as imbibe or absorb almost all the Rays of Light, must appear *dark* or *black*, *i. e.* without any Colour at all. Hence the Reason why *white Bodies* are of a *stronger and more lasting Texture* than *black Ones*, whose Parts being always subject to the Action of a much greater Quantity of Light, are sooner brought to a
State

State of Separation or Diffolution, *i. e.* of Rottenness.

30. Thus much for the *Rationale of Colours*; we shall next shew how VISION is *caused by the EYE*; in order to which we must first consider its *Form, Structure*, and other Circumstances conducive to this great Effect. *Fig. 10.* And first, since the *Nerves* are appointed the *general Organs of all animal Sensation*, the Eye being placed in the Head, a Portion of Nerves is sent from the Brain to each Eye, in a round Bundle, as NM; where it enters the Eye at M, and from thence is expanded into a fine Membrane or Lining over all the interior Part of the Eye as far as S and T: This Expansion of the optic Nerves is call'd the *Retina*, and is the *immediate Organ of Sight*.

31. For upon this the Rays of Light coming from every Point in an Object OB are convened by the *convex Figure* of the fore Part of the Eye KPL, and thereby an Image IM is form'd in the Focus, which in an Eye well form'd is nicely at the Bottom on the *Retina*. For this Purpose it was necessary the convex Part should be *transparent* to admit the Rays of Light freely; and thence it is call'd the *Cornea*, or *horny Coat* of the Eye.

32. In Order to keep this Cornea of a due Degree of Convexity, Nature has appointed a clear Fluid, lympid and transparent as *Water*, and is therefore call'd the *aqueous* or

watry Humour; this fills out the *Cornea*; and in Case it is lost by a Wound or Puncture in the *Cornea*, it is supplied again.

33. The next Part we meet with, is a Sort of Diaphragm or Membrane, call'd the *Uvea*, with a Perforation or Hole in the Middle at O O, call'd the *Pupil*: The *Pupil* is design'd to adjust the Quantity of Light for *distinct Vision*: For this Purpose, the *Uvea* consists of two Orders of *muscular Fibres*, one of a circular Form on the Outside, and by these the *Pupil* is contracted for the Exclusion of superfluous Rays, when the Object is too luminous and bright, And by another Set of Fibres on the Inside, disposed in a different Manner, like Radii from a Center, the *Pupil* is dilated to receive more Rays, when the Object is remote and dark.

34. Behind the *Uvea* we meet with a most curious Part S T call'd from its Clearness and Consistence, the *crystalline Humour*; it is like a small thick Glais Lens, more Convex behind than before. It is connected to the Coats of the Eye all around on the Inside by a Set of *muscular Fibres*, proceeding from the *Ligamentum Ciliare*, and is thereby suspended just behind the *Pupil*; it is included in a very fine Tunic call'd the *Arachnoides*: This Part is destin'd for correcting the first Refraction at the *Cornea*, and adjusting and perfecting the Image upon the *Retina*; which is done by occasionally altering its Distance from

the Retina, and the Convexity of its Surfaces, by the abovemention'd Ligament.

35. The Third and largest Humour of the Eye is call'd the *glassy Humour*; it makes the Globe or Body of the Eye, and is every Way very much like the *White of an Egg*: It is represented by the Space S I M T in the Figure of the Eye; and is very transparent. The Use of it is to give free Admission to Rays of Light to the *Retina*, which every where encompasses it, and to keep the Eye of a *globous Figure*. The Bottom of the Eye is not of a *plane*, nor yet of a *spherical Figure*; neither of which would admit of a true or perfect Formation of the Image on the *Retina*.

36. By this wonderful Structure and Mechanism of the Eye, the Image I M of any Object O B is form'd on the *Retina*, exactly in the Manner as by a Glass Lens, as shewn before from *Art. 15 to 20*. And tho' the Image be *inverted*, yet we must necessarily see the Object *erect*; because the *Idea of Position* depends upon the *Direction of the Ray of Light*; and as these Rays cross each other in the Pupil, it follows, that the Particle of Light at I, must excite the Idea of Vision at the Point B in the Object, it being refer'd thereto by the right-lined Direction of the Ray I B; and thus the Point M is refer'd to O, and so of all the Rest; whence the Object must necessarily appear erect.

37. The

37. The Nerve N M is not inserted in the Middle of the Bottom of the Eye, but on the Side, for this Reason, that all the Rays of Light that fall on the Part where the Nerve enters the Eye are lost, and had it been inserted at Q, just opposite to the Pupil, then all the Rays which enter the Eye directly, and make the most perfect Part of the Image I M had been lost, and we should have seen a Hole or black Spot in the Middle of all Objects; as we easily shew by Experiment.

38. When the *Cornea* K P L is too convex, the Rays of Light are converged to a Focus, before they arrive to the *Retina*, and therefore the Image upon the *Retina* must in that case be very indistinct and confused. Such an Eye is call'd a *Myops*, and makes *People short-sighted*, that is, it obliges them to hold what they see at a short Distance from their Eyes, in order to prolong the focal Distance, and make it reach the *Retina* to imprint the Image perfectly thereon. And for remote Objects they use a concave Glass which produces the same Effect, by causing the Rays to go less converging to the *Retina*.

39. When the *Cornea* is too flat, as generally happens by Age, the Rays tend to a Focus beyond the *Retina*; and this also causes the Image to be very imperfect and indistinct upon it; such People are therefore call'd *Presbytae*; and their Remedy is a pair of *Spectacles* with *convex Glasses*, which makes
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the Rays converge sooner, and imprints the Image duly on the *Retina*. Every thing hitherto advanced in regard to Vision, and the Defects thereof, together with their Remedies by Glasses, are shewn by the *Dissection of the natural Eye*, and *Experiments with an artificial Eye*, representing every Part, and the Effects of the natural Eye completely.

40. It now remains that we shew the Nature, Use, and Effects of the most considerable *optical Instruments*; the Principal of which are the MICROSCOPE, and the TELESCOPE. The first of these are so call'd from their representing Objects plainly to the View which by reason of their Smallness cannot be distinctly seen with the naked Eye. And *Telescopes* have their Name, from their perfecting, at least, improving our Vision of distant Objects, which appear under an Angle too small to be distinguish'd by the Eye alone.

41. Of MICROSCOPES there are three Sorts in Use, *viz.* The *single*, the *double*, and the *solar Microscope*. The Nature of the two First depends on these following Considerations, *viz.* (1) That we cannot distinctly see any Object at a *less Distance than six Inches from the Eye*. (2) * That the nearer any Object is, the larger is the Angle under which it is seen, and the Dimensions under which it appears. (3) That *parallel Rays*, or such as are nearly so, can only have their Focus at
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the Bottom of the Eye. And (4.) that any Object placed in the *Focus* of a *convex Lens* will have the Rays proceeding from it all refracted by the Lens parallel to each other, (See *Fig. 6.*)

Fig. 11.

42. Thus suppose A B a small Object placed in the *Focus* of the little Lens D E, and then all the Rays which proceed from any Point C in that Object will by the Lens be thrown parallel upon the Eye F, which therefore will produce distinct Vision of that Point; and since the same is to be observed of every other Point, 'tis evident the whole Object will be distinctly seen by Means of the Glafs.

43. Suppose the *focal Distance* C D to be *one Inch*, then will the Object be seen by the Glafs *six Times nearer* than it can be without it, (*Art. 41.*) therefore it will appear 6 Times *longer* and *wider*; * and 6 Times 6, or 36, Times larger in *Surface*; * and 6 Times 36, or 216 Times larger in *Bulk* or *Solidity* than it can appear to the naked Eye. But if C D be but $\frac{1}{6}$ of an Inch, the Object will be seen distinctly thro' the Lens 60 Times nearer than by the Eye alone; and therefore 60 Times *larger* and *wider*; 60 Times 60, or 3600 Times larger in *Surface*; and 216000 Times larger in *Bulk*; which tho' it be a prodigious Power of magnifying, yet these Glasses are common, and we have many of a much shorter focal Distance.

44. As

44. AS to the DOUBLE or COMPOUND MICROSCOPE, they consist of *two*, at least, but mostly of *three Lenses*; of the first or smallest C is placed near the small Object A B, viz. at a little more than its *focal Distance*; then will a large Image I H be form'd of the said Object; so much larger than the Object, as the Distance C I is greater than the Distance A C; and this Distance and Image may be made greater or less by placing the Object nearer to or farther from the Lens C. All which is evident from (*Art. 17, 18, 19.*)

45. Now this Image may be very distinctly view'd by any proper Lens, placed at its *focal Distance* from it, which Lens is call'd *Fig. 12.* the *Eye-Glass*; and to know how much the Object appears magnified by these two Lenses suppose the Distance of the Image C I to be 6 Times the Distance of the Object C A, then will the Length I H be 6 Times the Length A B, to the naked Eye; but this Length of the Image I H, if view'd by an *Eye-Glass* of an Inch focal Distance, will appear 6 Times as large as it does to the bare Eye, (*Art. 41, 43.*) Therefore the Image thus view'd, will appear 6 Times 6, or 36 Times *longer* than the Object A B; 36 Times 36, or 1296 Times larger in *Surface*; and in Solidity, 36 Times 1296, or 15552 Times larger than the Object.

46. But tho' the magnifying Power of this Microscope be very considerable, yet the Extent or Field of View is very small and confined; and therefore in order to enlarge it, and thereby render it more delightful another larger Lens D E is placed below, by which the Angle D C E or A C B, under which the visible Part of the Object lies, may be considerably enlarged; and the Image formed afresh at F G; which Image F G now lies within the two extreme parallel Rays of the *Eye-Glass* M F and N G, and is therefore wholly visible: Whereas before, only the Part O Q, which in the first dotted Image is contain'd between those Rays could be seen. And so tho' the Object be not quite so much magnified, yet it is magnified enough, and the visible Area very much encreased by the Interposition of this third Glass.

N. B. R S is a plain Mirrour to reflect the Light T, for illuminating the Object when transparent.

47. The Microscope constructed with three Glasses has been executed with great Success, and in many different Forms; all of which have two Parts, *viz.* one *internal*, containing the Glasses, and the other *external*, on which the Object is placed, and the Glass to illuminate it. Of these I contrived a very useful one for the Pocket, represented in Fig. 13. where A B C is the upper Part in Wood, Ivory, or Brass; containing the
two

Fig. 13.

two Eye-Glasses, *viz.* the Glass D E at C, and the other M N at B; the Object Lens C being contain'd in the Button H, which is rais'd up and down, and thereby adjusted to its due Distance, by Means of the Tube or Case I, which slides in the outward Part or Case C D E: In this there are two Apertures, one above where the Object is placed to be view'd in a small concave Lens at G. The other Aperture is the Hole F below, thro' which the Beam of Light T comes in, and is reflected by the Glass R S to the Object. It stands on a firm Basis E, and answers all the Ends of the largest Instrument of this Sort, with the utmost Ease.

48. The SOLAR MICROSCOPE is design'd to represent very small Objects extremely large in a *dark Room*, in the following Manner; A B is a Beam of the Sun's Light falling *Fig. 14.* on a Looking-Glass D C, so adjusted to a proper Inclination by two Brass Wheels, that it shall reflect the Ray parallel to the Horizon to a large convex Lens E F which converges them to a Focus; near which is placed the small Object G H, and is by that Means greatly illuminated; then a small Lens I is adjusted by a Screw to a little more than its focal Distance from the Object, by which Means a very large Image K L is thereby form'd on a White Wall or Sheet, on the opposite Side of the darken'd Room.

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48. The SOLAR MICROSCOPE is design'd to represent very small Objects extremely large in a *dark Room*, in the following Manner; A B is a Beam of the Sun's Light falling *Fig. 14* on a Looking-Glass DC, so adjusted to a proper Inclination by two Brass Wheels, that it shall reflect the Ray parallel to the Horizon to a large convex Lens EF which converges them to a Focus; near which is placed the small Object G H, and is by that Means greatly illuminated; then a small Lens I is adjusted by a Screw to a little more than its focal Distance from the Object, by which Means a very large Image K L is thereby form'd on a White Wall or Sheet, on the opposite Side of the darken'd Room.

49. The Power of magnifying in this Instrument is thus computed; Suppose the small Lens I is distant from the Object only $\frac{1}{10}$ of an Inch, when the Image K L is duly form'd on the Sheet, and suppose the Distance of the Sheet be 16 Feet from the said Lens; then in 16 Feet there is 192 Inches, and consequently 1920 Tenths of an Inch; then is the Length of the Object to the Length of the Image, as 1 to 1920, or the Object is magnified 1920 Times in Diameter, and 1920 Times 1920, that is 3086400 Times in Surface, *viz.* above *three Millions of Times*; and 1920 Times 3 Millions of Times in Solidity. Such is the prodigious and almost incredible Power of magnifying in this most curious optical Machine!

Fig. 15.

50. The TELESCOPE of the *refracting Sort* is of two different Structures, *viz.* One of four Lenses, the other of two. That which has four Lenses performs its Effects thus; Let O B be any distant Object to be view'd, and A D the Object-glass of the Telescope, and B Q the Axis of the Telescope. Let B I and O M be two Rays proceeding from the extreme Parts of the Object, and they will terminate the Image I M in the Focus of the Object Glass, as is evident from *Art. 18.* and *Fig. 7.* If a convex Lens E F be placed at its focal Distance from the Image I M, the Eye will thro' that Lens see the Image very distinctly, but in an inverted Position

Position. (*Art.* 19.) And therefore the Vision for terrestrial Objects will be very unpleasant; but for the heavenly Bodies, which are round, it will do very well; and in this Case it is call'd an *astronomical Telescope*.

51. But to view *Land-Objects* erect, another equally convex Glass H must be placed behind the former E F, at twice its focal Distance, that so the Rays which come from the extreme Parts of the Image I and M may cross each other in the Focus G, and falling upon the Lens H, may form by that Glass a *second Image* at its Focus K, which will be erect, or in the same Position as the Object O B, and may be distinctly seen by a third Lens L of the same Convexity as the two former, and placed at its focal Distance from the said second Image, by an Eye at Q in its Focus on the other Side. Fig. 16.

52. Since the Image I M, and the Object O B are both contain'd under equal Angles I C M and O C B, they will appear equally large to any Eye plac'd at the Object Glass C. But the Image I M, seen thro' the Glass E F is as much larger than what it appears when seen thro' the Lens A D, as the Distance C I is greater than the Distance I E (*Art.* 41.) And the second Image K N must necessarily be of the same Magnitude with the first, because the Ray M F terminates them both after Refraction at F and H, at equal Distance from the Axis: And therefore the Image

E

K N

K N must appear thro' the Lens at L, just as large as the Image I M will appear thro' the first Lens E F.

53. Suppose then the focal Distance I C of the Object Lens be 3 Feet or 36 Inches; and the focal Distance of the Eye-Lens be 2 Inches; then since 2 is contain'd 18 Times in 36, such a Telescope will *magnify* 18 Times. If the Eye-Lens were $1\frac{1}{2}$ Inch focal Distance, then $1\frac{1}{2}$ 36 (24 or it will in this Case magnify 24 Times. If it were one Inch only, the Object would be magnified 36 Times, or appear so many Times nearer thro' the Telescope than it does to the naked Eye.

Fig. 17. 54. There is a Construction of a Telescope *with two Lenses only* to view an Object upright. Of these the Object-Lens C D is a *Convex*, as before, but the Eye-Lens G E is a *Concave*. And thus supposing A B parallel Rays falling on the Lens C D they will thereby proceed converging to the Focus of the said Lens at F; but if they are intercepted by the Concave G E placed at its focal Distance from the Point F, then will the Rays be refracted thro' it parallel to the Axis, and as such they will produce distinct Vision. See *Art. 21.* and 41.

55. The Image is not actually form'd by this Telescope, and the Object must appear in its true Position, because there is no *crossing of Rays* in their Passage thro' this Telescope. And if the focal Distance of the Lenses

Lenses in this are the same as in the other Telescope, the magnifying Power will be the same. But the Misfortune of this Telescope is, that the *Field of View* is *very small*, and cannot be increas'd but by diminishing the magnifying Power; and is therefore seldom used but in short Lengths, and for viewing *very near Objects*.

56. As the two Sides of a convex Lens contain an Angle somewhat in the Manner of the two Sides of a Prism; it must follow, that as in the Prism, so in the Lens, the Rays of Light will be refracted in a different Manner, and to different Parts of the Axis; and therefore when the Image is view'd by an Eye-glass with a *very short focal Distance*, it must appear *obscure, indistinct, and tinged with various Colours*; this Imperfection of refracting Telescopes is in a great Measure remedied by the Invention of *reflecting Ones*. The Theory of which, in short, is this.

56. Let A B C D represent the Tube of Fig. 18. a reflecting Telescope, E F the large reflecting concave Mirrour, with a Hole H O in the Middle of it, placed at the inmost End, and let *g h* be the small Concave placed at the other End upon a Foot or Stem; by which, and a Screw on the Outside, it is moveable backwards or forwards as Occasion requires. Let *a b*, *d c*, be two parallel Rays of the Sun's Light, falling on the great Speculum, and by it reflected to its

E 2

Focus

Focus f , where the Sun's Image will be form'd in a small round Spot. If that by Means of the Screw the small Mirrour $g\ b$ be moved to a little more than its focal Distance from the Image of the Sun at f , the Rays which go from it to the Speculum $g\ b$, will by it be reflected thro' the Hole HO in the large one, to a plano-convex Glass behind it IK , which will cause a second and much larger Image to be form'd in the Part LM in the Tube behind; this second Image is view'd by the *Meniscus* Eye-glass, placed in the Part $N\ Q$ by parallel Rays passing thro' a small Hole to the Eye at R .

58. But as this is a very complex and intricate Calculation, I must refer the Reader to my *Philosophia Britannica*, for the Method of computing the magnifying Power of this Instrument, and shall here only observe, that it is so great that a reflecting Telescope, whose focal Distance of the great Mirrour is any Number of *Inches*, will generally magnify as much as a refracting Telescope which is as many *Feet* in Length. I might also here observe, that this Instrument is as well adapted for a Microscope as a Telescope, but this is best shewn by Experiment, and that in different Ways.

59. There is a Method of applying either the refracting or reflecting Telescope in a dark Room for viewing the *Spots in the Sun*, the *Eclipses of the Sun*, the beautiful Colours
of

of the Clouds, &c. &c. But for this Purpose the Refracter is best, and may be properly call'd the *Solar-Telescope*. This likewise we shew in all these Cases by Experiments in the *Camera Obscura*.





SECTION III.

The Nature and Properties of AIR explain'd; the artificial Production of AIR; of the TRANSPARENCY, ELASTICITY, and GRAVITY of the Air; of BAROMETERS, THERMOMETERS, and HYGROMETERS; the Construction and Use of a NEW PORTABLE AIR-PUMP; a select Number of principal Experiments thereon, to illustrate the Qualities and Uses of the Air.

1. **T**HE Business of this Section will be to discourse of the *Nature, Origin, and Properties* of AIR; and the Description and Use of those *Instruments and Machines* by which they are demonstrated in a *Course of Experiments*, according to the modern Improvements and Discoveries.

2. The Nature of AIR consists in the following Particulars, (1.) Extreme *Subtilty* or *Smallness* of its Particles. (2.) The *Invisibilty* of its Parts, and the *Transparency* thence arising. (3) Its *Springiness* or *Elasticity*.

slicity. (4) Its *Weight*, or *Gravity*. (5.) The *Vivifying Spirit* it contains, so necessary to the *Life of Animals, Vegetation, &c.*

3. As to the first Property of Air, which consists in the extreme *Minuteness* or *Smallness* of its Particles, I observ'd in the first Sect. (*Art.* 32.) that this was a necessary Consequence of the Manner in which it was generated, *viz.* by a gentle imperceptible Fermentation in all Bodies, which again proceeds from their *natural Warmth* or *Heat*, which arises wholly from the *Action of Light* imbibed by Bodies, (*Seet.* II. *Art.* 5.) by which their Parts are put into an intestine Motion; and those on the Surface being constantly agitated, are by degrees thrown out of, or beyond the *Sphere of corpuscular Attraction*, and then immediately repell'd from the Body in an Efflux or *Effluvium* of Particles too small to be visible to the Eye.

4. But in Order to shew that this is the true and real Method in which Air is generated from Bodies, and at the same Time to render it visible to the Eye, the following Experiment has been contrived. A B C is a Glass Tube of a considerable Length and Diameter, with a very small Hole at the lower End at B. When this Tube is fill'd full with Water, and stop'd close on the Top with the Thumb, the Water will not run out at the whole B, being there supported by the Pressure of the external Air, which is

Fig. 1.

E 4

greater

greater upward than the Pressure or Weight of the Water downwards. But if the Thumb be lifted up, it runs out; the Pressure of the Air being then at Top and Bottom equal.

5. If now the Tube be fill'd with Water, render'd *acid* by a little *Aqua-fortis*, and a Piece of Chalk D put into it; the Chalk being an *Alkali*, will ferment with the acid Mixture, and thereby generate a very large Quantity of Air, which will be seen to rise thro' the Liquor to the Top of the Tube, (which is now close stop'd with a Cork, as shewn in *Fig. 1.*) in innumerable Bubbles, which breaking above the Surface EF, will become *one uniform elastic Body of Air*, which by its Spring will press upon the Fluid below and force it all by degrees thro' the small Hole at the Bottom B.

6. Now since the Tube is at first wholly fill'd with the Fluid, and the Air that is generated, forces it all out in Opposition to the Pressure of the outward Air, it plainly appears, *that the Spring of this new generated Air, is greater than the Spring of the common Air*, and is in every Respect of the same Nature with it. And from hence it appears how the common Air is generated from all other Bodies by a like Fermentation, tho' not perceptible to the Eye, as it here is by means of the denser Medium of the Liquor.

7. From this Experiment we learn, that *Air*, in its natural State is fix'd, and makes

a Part of the common Substance of Bodies, and is a kind of *natural Cement*, which binds the Parts of Matter together; because we observe, that as fast as the fix'd Air is discharg'd and set at Liberty, the Particles of the Body lose their natural Cohesion, and fall off in the Form of a fine Powder or Dust to the Bottom, and so far the Body becomes dissolved; and the same may be observed in the common Solution of all other Bodies, in every sort of dissolving *Mensstruum*.

8. And what is very observable farther in this Experiment is, that this *artificial Air*, in its natural fix'd State makes a great Part of the Substance of Bodies. For if we allow $\frac{2}{7}$ of a Grain for the Weight of a Cubic Inch of Air in its elastic State, (as will hereafter appear to be the Case) then by this Experiment tried in a very large Tube, it will be found, that the Air thus produced, will amount to a very large Proportion of the Weight of Bodies thus dissolved. And thus particularly the *Stone in the human Bladder*, has been found to yield so much Air, as has amounted to more than half its Weight.

9. From hence may be deduced the Con- Fig. 2.
trivance of an *artificial Air-Gun*, or *Pistol in Glafs*, as A B C E F, consisting of a Body G C H, and a Barrel, A B E F, somewhat like a Retort: If the Body be fill'd, the greatest Part, with the before-mention'd acid Mixture, and a Piece of Chalk D put into it;
and

and then it be charged with a small Piece of Cork with Lead in it, as B E, the Fermentation will produce so much *elastic Air* above the Surface of the Liquor G H, as at last shall expel the Bullet B E with a prodigious Force, like that of Gunpowder, to a very great Distance K.

10. From this Experiment also we learn the Reason why, in bottled Beer, Ale, Syder, &c. the Corks often fly, and the Bottles burst, *viz.* with the elastic Air generated by a slow Fermentation in those Liquors. Also the Reason of those Eructations of Wind from the Stomach; of *Flatulencies* and cholicky Disorders in the Bowels, which are all nothing more than the Air generated by Fermentation, arising from the Mixture of what we eat and drink, with the natural Juices of the Body.

11. The INVISIBILITY of the Particles of Air, is the Cause of its *Transparency*; and this a necessary Quality, inasmuch as we could not have been able to have discern'd Objects thro' it with any degree of Clearness and Distinction, had it been in any Measure opaque. This appears by viewing Objects thro' Telescopes of a large magnifying Power, which at the same Time magnify the Particles or Body of Air, and cause Objects seen thro' it to appear very misty and confused. Hence also it appears, that the

the Air thus magnify'd, sets Bounds to the Improvement of Telescopes.

12. The Body of Air, consider'd as a Sphere of elastic Vapours, sublimed from Bodies, extends or expands itself to a very great Distance or Height from the Earth every way; and is every where of a different decreasing Density. For the Air being every where compress'd with the Weight of the super-incumbent Air, must have its Density proportional to that Pressure; and therefore decreasing upwards in the same Ratio as the Air's Height, Gravity, or Pressure decreases.

13. Were the Density of the Air every *Fig. 3.* where the same, it would be very easy to determine its Height by the following Experiment. A B C D is a Vial fill'd with Water to the Height E F, in which is immersed a Glass Tube I G, open at both Ends, and cemented to the Vial at A D, to cut off the Communication of Air. This done, a little Air is blown thro' the Tube, which mixing with the Air in the Part A E F D, will condense it, and of course encrease its Spring or Pressure; this will raise a Column of Water into the Tube to the Height H, such that its Weight, together with the Weight of the Column of Air above it, be equal to the Spring of the included Air; and then an *Equilibrium* between them will ensue.

14. If now the Vial, thus prepared, be carried up any high Place, as a *Tower, Hill,*
&c.

&c. it will be seen, that for every 72 Feet you advance, the Surface H will rise *just one Inch* in the Tube. Now since this one Inch of Water rises to compensate the Deficiency of Pressure in the Column of Air over it, now shorten'd 72 Feet, and since (as we shall make appear hereafter) the whole Weight of the Air will raise a Column of Water 32 Feet, or 384 Inches, 'tis evident if we multiply 384 by 72, it will give the Number of Feet (*viz.* 27648) which would assign the Height of the Atmosphere uniformly dense, which is about $5 \frac{1}{4}$ Miles.

15. This Experiment also most accurately assigns the *comparative Gravities of Air and Water*; for since it appears, that one Inch of Water countervails 72 Feet, or 864 Inches of Water, and the Gravities of Fluids acting against each other are inversely as their Altitudes, (as it hereafter appears) it follows, *that the Density of Air is to that of Water, as 1 to 864 precisely*

16. This Instrument also presents us with one of the most easy and perfect extemporaneous *Thermometers* that can be contrived. For since the Column of Water G H is supported by the very yielding and tender Spring of the included Air pressing upon the Surface E F, it will *rise and fall* with the *least Expansion or Contraction* of that Body of Air by *Heat and Cold*. Thus if the *Hand* be applied to the Vial, it will rise several Inches; and

and if it be immerfed in *cold Water*, it will defcend thro' many more. Thus alfo it is fitted for difcovering the *small Differences of Heat and Cold* in different Rooms of a Houfe. Thus alfo it is applicable to *Stoves, Hot-Houfes, Hot-Beds, &c.*

17. But, as I faid, it is fit only for *extemporary* or *prefent Ufe*; becaufe the upper Surface H being prefs'd with the Air above it, if the Gravity of the Air be alter'd, it will rife and fall by that Means, tho' we fuppofe the Warmth of the Room to remain the fame all the while. And therefore it cannot be depended upon as a *Thermometer*, for any long Time together.

18. And as the *Heat and Cold of Air* is the Bafis of the curious and useful *Invention of Thermometers*, which are Instruments to meafure the various Degrees thereof, I fhall explain in a few Words the Nature and Ufe of them. It is well known, that all Bodies, whether *fluid or folid, expand with Heat, and contract with Cold*, and therefore may be made ufe of for this Purpofe. But *Fluids* are the moft proper Subject; and amongst them *Spirits, Oil, and Mercury* have the Preference, but efpecially the latter, on the following Accounts. (1) *Mercury* does not filth or foul the Tube in which it is contain'd, as tinged Spirits and Oil do. (2.) It expands and contracts much more fpeedily than either of the other (3.) It is fufceptible

tible of vastly greater Degrees of Heat and Cold, than any other Fluid whatsoever.

Fig. 4.

19. The *mercurial Thermometer* is a fine capillary Tube A B, with a round or oblong Bulb B C, fill'd with Mercury to a proper Height as F. Here, since the Bore of the Tube is exceeding small, the Motion of the Mercury up and down in it, by the least Expansion or Contraction of that in the Bulb, will be very sensible; and a Scale of equal Parts D E, being placed by it, the various Degrees of Heat and Cold will be easily discern'd and compar'd by the Numbers in the Scale, against which the Point F shall at any Time stand.

20. Since *Heat and Cold* are only relative Terms or Ideas, there is a *common Standard* or *Boundary* to which they must be referr'd, and from whence their Quantity on each Side must be estimated, by the Parts of the Scale affix'd to it. And this common Limit of *Heat and Cold* can be no other, with respect to us, than that *particular Degree* or *Temperature* of the Air when we say, *it is neither warm nor cold*; or that which is equal to the natural Warmth of the external Part of the Body.

21. Now from this *Point of Temperature*, the Divisions of the Scale ought to begin, as in the Figure, and to be continued both Ways; and then the various Degrees of Heat may be compared, as to their Excesses or
Diffe-

Differences from that of Temperature, very easily, thus : If any Degree of Heat A, shall raise the Mercury 10 Parts, and another Degree B, raise it 20, and a Third Degree C, raise it 30, then will these Numbers 10, 20, and 30, or 1, 2, 3, undoubtedly express the Ratio's of the Intensities of those Degrees of Heat, or the Sensations we have of their Effects.

22. Thus, on the other Hand, we may judge of the various Degrees of Cold, or rather of those Degrees of Warmth which are *less than temperate*, or that of the Hand. If it *freeze* when the Mercury is 10 Degrees below temperate, it will be *twice as cold* when it stands 20 Degrees below, and so on. Tho' this be a Method sufficient for one's own private Use, yet when it is necessary to communicate one's Observations of this Kind, to others who make the same at a Distance, and upon *different Thermometers*, there ought to be one common Number of Parts agreed upon between *two such Points as are constant* in all Thermometers; and it is found, that none are more so than the Points of *freezing* and *boiling Water*.

23. This being consider'd, and the Learned having generally a Regard to *Farenheit's Scale*, in which the *freezing Point* is at 32, and that of *boiling Water* 212, so that between them there is 180; if then the same Number 180 be reckon'd between the same
two

two Points in any other Scale, they may all be compar'd with this, and consequently with one another. Or thus, by the *Rule of Three*: Suppose the Thermometer in the Figure contains 80 Degrees between those two Points, and that any particular Heat raises the Quicksilver to 20 above *freezing*, then say, as 80 : 20 :: 180 : 45 ; to 45 add 32, and the Sum is 77, which is the Number to which the Mercury stands in *Fahrenheit's Scale*.

24. The Air has another Quality, *viz.* of various Degrees of *Moisture and Dryness*, as it is always more or less replete with *aqueous Particles* or *watry Vapours* ; and since the human Frame is thereby very much affected in regard to Health, it has occasion'd the Contrivance of various Instruments call'd **HYGROMETERS**, for measuring the Degrees thereof, of which I have elsewhere given a large Account. But I shall describe one of a late Invention, which seems well calculated to answer this Purpose. It has been observ'd, that Boards swell and contract very much *width-ways*, by the Moisture and Dryness of the Air ; and from thence it was inferr'd, if a Board was saw'd across the Grain into several Pieces about an Inch wide, and these Pieces all glued together at their Ends, they would make one long Slip that would admit of a considerable Degree of Expansion and

CON-

Contraction in Length, such as represented by A B in the Figure.

25. If this Piece be fix'd in an upright Position, with a Cord D E going over a moveable Pully C, carrying an Index I over the graduating Limb of a Quadrant G H, and tended with a weight F, it is evident, that as the Piece A B extends in Length by the Moisture entering the Pores of it, the Index must go forwards; and as it contracts with Dryness, the Index will move backwards, and thereby measure the various Degrees of these Qualities of the Air. The Piece should be first put up as dry as possible, and the Index then set to the Beginning of the Degrees at G, and then the several Degrees of Moisture will afterwards move it from thence towards H. But this Piece of Wood is applicable to greater Perfection in an Instrument call'd the *Pyrometer*, to be hereafter described.

26. The Air is also a very heavy or ponderous Body; for its Parts, tho' small, gravitate in this their separate State, as much as when fix'd in Bodies, by Virtue of the Earth's Attraction. And therefore, like all other Bodies, *the Air gravitates in proportion to its Quantity of Matter.*

27. But as was observ'd in the first Section, the Air consists of very different Kinds of Matter, which makes it sometimes *lighter*, sometimes *heavier*, according to its constituent

F

tuent

tuent Matter. Thus when the Air abounds with *aqueous Parts*, it will become much lighter than when it consists of Particles derived from dry, solid, heavy Bodies, which makes the *dryest, finest, and heaviest Air*. The Reason of this has been shewn in *Seet. I. Art. 35. Fig. 8.*

28. As the *Air* is by Nature appointed the necessary Means of Respiration; and as an elastic heavy Air is of much more Force to *expand the Lungs*, and to *impregnate the Blood with its enlivening Spirit*, than the Air which is weaker and lighter, it imports us greatly to be well acquainted with the *Air's Gravity*, and the *Alterations* it continually undergoes in that respect, especially too, as it must necessarily have a Relation to the State of the *Weather*, and *all its Variations*, of which it is in a great Measure the Cause (See *Seet. I. Art. 36*) I say, upon these Accounts, it is no Wonder if ingenious Men have long been in the Pursuit of the most easy and expressive Methods and Instruments to indicate this Affair.

29. And various have been their Inventions for this Purpose; and BAROMETERS have been multiplied in numerous different Forms. But after having examined them all, I am firmly persuaded there is none that comes up to that which was first of all invented, either for *Easiness of Structure*, *Simplicity of Parts*, and *Accurateness of Use*;
and

and is made in the following Manner. A B is a Glass Tube about 33 or 34 Inches long, and whose Bore is about $\frac{1}{4}$ of an Inch Diameter. It is hermetically closed at the End A, and at the open End B, it is fill'd quite full of very clean, pure Mercury; then whilst it is thus full, it is inverted, with the End B stop'd, into a wide Bason of Mercury E C D F, and then the End B being unstop'd, the Mercury will subside from the Top A, and stand at a certain Height B I in the Tube. Fig. 6.

30. By this Means the Space above the Mercury A I is left devoid of Air, or a *Vacuum*; and the Column of Mercury in the Tube B I, is sustain'd solely by the Gravity of the Air, or its Pressure on the Mercury in the Bason, which arises from thence; as evidently appears from an Experiment of taking the Air away by the Pump, and in proportion as it is exhausted, the Mercury will sink towards the Bottom. *This Column of Mercury therefore, is an Equipoise to a Column of Air of the same Base and Height of the Atmosphere,* and of course the Weight of both must be the same.

31. Therefore whenever the Gravity of the Air shall alter, the Column B I will also alter its Height, and so when the Air becomes heavier, it will rise higher, and as the Air becomes lighter, it will sink lower: And it is found by Experience, that when lightest of all, it sinks not much below the Height

of 28 Inches, and when *heaviest*, it rises not higher than 31 Inches; and it very rarely comes to either of these Extremes, the *mean Height* being nearly 29 Inches. All which is easily observed by a Scale of Inches applied to the Tube, as is represented in the Figure.

32. If the Tube A B were of a square Form, and just a *square Inch* Area in the Bore, the Mercury would rise to the same Height, at a Mean, 29 Inches; so that in such a Tube, there would be 29 cubic Inches of Mercury; and every such cubic Inch weighs $8\frac{1}{10}$ oz. Avoirdupois; therefore the Weight of such a Column of Mercury, and consequently of a Column of Air of the same Base, will be equal to about 14 lb. Weight; and so upon every *square Foot*, it will be 14 Times 144, or 2016 lb. and somewhat more; and if we allow about $14\frac{1}{2}$ square Feet upon the Surface of a middle-siz'd Man, it will follow, that such a Man sustains a Pressure of Air equal to 2016 Times $14\frac{1}{2}$ lb. or nearly 30000 lb. which is nearly 14 Tons.

33. The Reason why we are not sensible of so very great a Pressure, is because our Bodies are fill'd with Air throughout, and the Spring of the internal Air is every way equal to the Pressure; and therefore every Part of the Body being acted upon by a Force on every Side equal, it cannot be sensible of any Force at all, either of Spring or Pressure; but if one of those Forces be suspended in
any

any small Degree, the other becomes immediately very sensible, as we shew by an Experiment on the Pump to explain the Nature of *Cupping*.

34. Hence since the Difference between the least and greatest Height of the Quick-silver in the Tube, is 3 Inches, it follows, that when the Air is heaviest, we sustain a Pressure of more than a tenth Part of the whole greater than when it is lightest, which is more than a Ton Weight. And therefore it is easy to see the Reason why a *light Air* affects *asthmatic People*, and other *Valetudinarians*, in so very sensible a Manner, as we find by Experience it always does. The air when so light, not having the Force to *expand the Lungs*, to *brace the Fibres*, to *promote the Circulation*, to *open Obstructions*, and *produce a free Perspiration*, as when it has a greater *Weight and Elasticity*.

35. We are by this Instrument moreover enabled to predict the *Alteration of Weather*; for when we see the Mercury falling, we know the *Air is lighter*; we know by that it must be fill'd with aqueous Particles; we know also from thence that Clouds, Storms, Rain and Wind must ensue; and the contrary. And hence the *great Use*, yea, *Necessity* of these Instruments to all who are any way concern'd with the *different State and Alteration of the Weather*. And it is not difficult
for

for every one to find that he is more or less affected by it.

36. These are the different Instruments that indicate the various Qualities of the Air. But the *Grand Machine* of all, by which the several Properties of Air are in a most wonderful and entertaining Manner render'd sensible to us, is the AIR PUMP. This Machine has undergone various Forms and Changes since its first Invention by *Otto Gueric*, a German; by *Boyle*, *Haukeſby*, *Davenport*, &c. But as I have contriv'd one different from them all, far more concise and easy to be used, I shall here give a Description of it, as follows. A B is the Frame or Head, in which is contained a Wheel, which by Means of Chains on each Side, moves the two Pistons C, D, up and down alternately in the Brass Barrels E F, which are strongly screw'd down on the two Pillars G H, fix'd in the Bed or Bottom Part I K. On this Part in the Middle is let in a large smooth Brass Plate, with a Hole in the Middle, upon which Plate the *Receiver* M N is placed. From this Hole under the Receiver there is a Perforation or Canal thro' the Brasses to the fore Part O, where there is adapted a Screw to let the Air into the Receiver when drawn out.

Fig. 7.

37. From the above-mention'd Canal, there is also a Perforation through the Brasses to the Center of the Basis of each Barrel, in

in which Center there are fix'd Valves opening upwards to give Passage for the Air into the Barrels; and in each Piston there is another Valve opening upwards also, that the Air now in the lower Part of the Barrel may escape that way out into the common Air. Hence the *Rationale* of Working in this Pump must be very plain.

38. For each Piston, being nicely fitted to the Barrel, and working in Leather and Oil, is very *Air-tight*; and therefore when lifted from the bottom of the Barrel, the Column of Air above is lifted up, or off from the Valve, and the little remaining Air in the Barrel below being thus greatly rarified, it's Spring is but weak, and therefore the Air from the Receiver must necessarily rush in through the Valve to make the Air in the Barrel of the same Density as the common Air. Then when the Piston is forced down the Air below can't go back, but will readily rush upwards thro' the Valve in the Piston. And thus each stroke of the Pistons diminishes the Air in the Receiver till the whole be nearly exhausted.

39. On the Middle between the two Barrels there is a Hole in the Brass communicating with the Receiver, and over this Hole is placed a small Receiver P Q, and under it a small Basin R with Mercury, in which a small Tube R S, sealed at the End S, and fill'd with Mercury, is inverted. And

as the Air is taken out of this small Receiver at the same time as the large one is exhausted, the Approach towards a *Vacuum* will be clearly seen by the gradual Descent of the Mercury out of the Tube into the Bason. And such is the Structure and Form of an *Air Pump*, that contains no Parts but what are essential, and therefore cannot admit of farther Improvement.

40. I shall now proceed to give an Account of the capital Experiments which are shewn upon it; and first, a small Glass is inverted over the Hole of the Plate, and the Air within exhausted; it is then press'd very fast to the Plate by the Weight of the incumbent Air, and requires a great Force to pull it up.

41. That this is not owing to any thing within the Glass, drawing it down thro' the Hole, and which is commonly call'd *Suction*, is thus proved; let the Glass be set inverted on one Side the Hole, and covered with a Receiver; then upon exhausting the Air will get out of the small Glass by its spring; when the Air is let in again, it will fall upon the small Glass, and press it down as fast as before.

42. The Manner in which the Air discharges itself from any Body, is shewn by a large empty Glass Bubble with a Neck immersed in a Glass of Water; and then cover'd with a Receiver. Upon exhausting the
Air

Air will be seen to throw itself out through the Water in a pleasant Manner, and upon letting the Air in again, it will fall on the Water and force it into the Bubble, so that the remaining Air is now compress'd into a very small Space at the Top.

43. Then to shew the *Force of the Air's Spring is equal to that of its Pressure*, this Glass Bubble of Water and Air is placed under the Receiver upon an empty Glass; and upon exhausting the Air, the Air Bubble above the Water will expand itself by degrees and force out all the Water, which was driven into it by the Air's Pressure.

44. In like Manner, there is a Bubble of Air contained in the great End of an Egg, betwixt the Skin and the Shell; if therefore a Hole be made in the little End, and the Egg placed on a Glass under the Receiver, it will appear, that upon pumping, the Air will expand itself so far as to drive out all the Contents of the Egg thro' the Hole in the little End.

45. And by taking off half the Shell, putting the Remainder under the Receiver, and exhausting the Air, the Air that is contained under the Skin (or *Putamen*) will raise it up and protrude it sometimes so far out as to resemble an entire Egg.

46. If an Egg be put into a small Jar of Water, and cover'd with the Recipient, upon exhausting you will see the Air in a very

very beautiful Manner rise in little Jets or Streams through the Water from the Pores of the Egg; which shews how the Air by the natural Heat of the Weather gradually escapes from the Egg, by which Means it becomes by degrees *stale, putrid, and addle*; and therefore to preserve Eggs good for a long Time, the best way is to varnish them over with a hard Varnish, which will glue up the Pores and prevent the Air in the Egg making its Escape.

47. If a shrivell'd Apple be placed under the Receiver, and the Air exhausted, the Air contain'd in the Apple will expand itself and the Apple, and thereby cause the Wrinkles to disappear, and the Apple will now appear plump and fair as when first gather'd nearly. Upon letting in the Air, the Apple becomes again shrivell'd, and more so than at first.

48. If such an Apple be prick'd full of Holes with a Pin, and put into the Jar of Water under the Receiver, and the Air exhausted, then great Numbers of fine *Jets of Air* will be seen to rise from the Apple through the Water, as before in the Egg; which will all disappear by letting the Air in again.

49. If a Jar of clear Water be placed under the Receiver and the Air exhausted, the Bubbles of Air contain'd in the Water, will now begin to expand themselves, and arise in

in great Plenty from all Parts of the Water, and in a very visible Manner.

50. If a Jar of new Beer or Ale be placed under the Receiver, upon exhausting, the Air in the Beer will rise in a very copious Manner from all Parts, and expand into innumerable Bubbles, which as they are lined with the viscid Particles of the Beer, will be thereby prevented from bursting, as they do in Water, and by this Means they will appear in the Form of a *large frothy Head* to the Top of the Glass.

51. If some very hot Water be put into a Glass Jar or Vial, and plac'd under the Receiver when the Air is sufficiently drawn out, the Heat will cause the Air in the Water to expand itself into such large Volumes or Bubbles, and with so much Violence, as will put the Water into a great Agitation, and produce the Appearance of *Boiling* to a surprizing Degree. A much less Degree of Heat being now sufficient for that Purpose, than when it is under the Compression of the Atmosphere, over the Fire.

52. If a Piece of Wood of any Sort be fix'd to a Weight, and immersed in a Jar of Water under the Receiver, then upon exhausting, the Air contain'd in the Pores of the Wood will be seen to arise from it in so great a Quantity and such fine Streams, as nearly resembles the Smoke from a Chimney.

53. If

53. If a long Piece of Wood be fixed with Leathers to the Top of an open Receiver, so that one Part be out, and the other in the Receiver, and immersed in a Glass of Water ; then putting your Thumb upon the Top of the Wood to shut off the Air, begin to exhaust, and the Air contained in the Pores will be seen to rush thro' the Water as before ; but now lift up your Thumb, and you'll see a vast Quantity of Air flow thro' all the Length of the Wood from without. And by lifting the Thumb off and on, several Times, the Influx of Air will as often appear and be as often interrupted. And by this Experiment it appears, that there are *no lateral Pores* in the Wood by which the Air can enter into the Receiver.

54. Again, fitting a Piece of Wood with Cement into one End of a Brass Ferril, and placing it with Leathers on the Top of the same Receiver, fill the upper and open Part of the Ferril with Mercury, then exhaust the Air from within, and the Air pressing on the Mercury without will force it thro' the Pores of the Wood in such fine Streams as will represent a *beautiful Shower of Mercury* in the Receiver.

55. Let a Piece of Wood be cut smooth at each End, and immersed in a small Bason of Mercury under the Receiver, upon exhausting, the Air will all fly out of the Pores thro' the Mercury, and letting the Air in again,

again it will fall with so much Force upon the Mercury as to inject it thro' all the Pores of the Wood so very nicely, that the Wood will now appear quite *blue*, and be much *heavier than before*.

56. If a Bladder nearly emptied of Air, and fast tied, be put under the Receiver and the Air extracted; the small Quantity of Air remaining in the Bladder will expand it by Degrees, and at last fill the whole to its utmost Dimensions. And indeed the smallest Quantity of Air will fill the largest Space by Expansion.

57. If the Hand be laid upon the Top of an open Receiver, as the Air is exhausting, you will observe and very sensibly feel the Spring of the Air in the Hand, forcing the Flesh down into the Glass; also the Weight of the Air on the Back of the Hand will have a visible Effect in pressing down the Skin and Flesh between the metacarpal Bones. This Experiment full explains the Nature of *Cupping*.

58. The Weight of the Air is more directly shewn, and its Quantity estimated, by weighing it in a Ballance as we do other Bodies. Thus a *Florence* Flask with a Valve fitted on the Top is exhausted under the Receiver, and while thus empty, it is equipoised with Weights in a fine Hydrostatic Ballance; then lifting up the Valve, the Air re-enters the Flask, and by its Weight
carries

carries it down ; then the Number of Grains put into the other Scale to restore the Equilibrium is the Weight of that Air which fills the Bottle. And this I find to be nearly *Eight Grains* for a *Pint*, or a *Dram* for a *Gallon*, or an *Ounce Troy* for a *Busbel*.

59. To shew the great Force of Compression, I take *two hollow Brass Hemispheres* of 4 Inches Diameter, which contain a circular Area of $12\frac{1}{2}$ square Inches ; these being properly put together and exhausted, will require the Force of *two strong Men* to pull them asunder ; or 180 lb. to separate them on the *Steel Yard* ; which is about 15 lb. to a *square Inch* (See *Art* 32.)

60. The *Air* is the Medium that *propagates Sound* ; as appears by placing a Bell under the Receiver ; for then when it is rung, you scarcely hear the Sound, even tho' the Receiver be not exhausted ; but when the Air is drawn out, you can hear no Sound at all. SOUND consisting in nothing more than a *pulsive Motion* of the Air, excited by the Tremours of the sounding Body, and striking upon the Drum of the Ear puts the internal Air into Motion upon the Expansion of the *auditory Nerve*, by which Means the Ideas of Sound are raised in the Mind.

61. The Air is also necessary for *Fire* and *Flame* ; since a Candle, live Coal, &c, instantly go out under the exhausted Receiver. Also *Gun-Powder* will not explode or flash in
Vacuo,

Vacuo, nor any *Sparks of Fire* be seen from the *Flint and Steel* in that Case.

62. But the greatest Necessity and Importance of Air is for *animal Respiration*; especially all the larger Sort, which immediately die upon exhausting it; and tho' *Insects*, *Reptiles*, *aquatic Animals*, &c. will not die (at least under a long Time) in *Vacuo*; yet they seem to undergo some very painful Sensations, when the Air is taken from them, as is evident from divers Experiments of this Sort.

63. Tho' a common Animal soon dies by exhausting the Air, yet if it be let in again before the Blood becomes stagnant, it will expand the Lungs, and permit the Blood to circulate through them again; upon which the Animal will revive, and appear in a few Minutes but little the worse for such a *temporary Death*.

64. If a Receiver be exhausted, and the Air let in again thro' a *Charcoal Fire*, it will thereby have its *vivifying Quality* destroy'd; for a Candle instantly goes out in it, and a Bird falls down dead very suddenly; it seems to be infected like that we call *Damps* in the Bottoms of deep Pits, Mines, &c. which produces the same Kind of Effects. And it is known by too many Instances, how deleterious a *Charcoal Fire* renders the Air of a common Room when confined. It is remarkable that no common Coal
or

Wood Fire will produce this Effect; and that the Air in passing thro' the the *Charcoal Fire* has none of its sensible Qualities alter'd.

65. Lastly, that the lightest Body falls as soon as the heaviest *in vacuo*, is shewn by a Guinea and Feather falling in the same Time from the Top to the Bottom of a tall Receiver. For where there is no *resisting Medium*, there can be nothing to cause any Difference in the Time of the Fall, since every Particle in both Bodies being urged with the same Force downwards, they must necessarily all go with the *same Velocity*.

66. These are most of the capital Experiments of the *Air-Pump*, and demonstrate all the important Properties of the Air. They who would see much more may have Recourse to my *Philosophia Britannica*. I shall conclude this Part with observing to the Reader that the Way in which the Air is exhausted, may be render'd visible to the Eye by the following Contrivance. Let A B C D be a Tube of Glass, screw'd in at the Bottom to a Receiver R, in form of a Cupping-Glass. In this Glass Barrel let Water stand over the Valve V to the Height of about 2 Inches C E F D. Also let Water be put over the Piston G H I K, to the Height L M; then 'tis evident, that when the Piston is placed on the Surface of
Water

Fig. 8.

Water below at E F, and raised up again, the Air from the Receiver R will rush up thro' the Valve V, and all the Water above it in a very pleasant and visible Manner, to fill the Space below the Piston. This Air must again upon the Descent of the Piston rise up thro' its Valve, and all the Water above, as before; all which is so plainly represented in the Figure as to require no further Description.



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SECTION



Of the various SYSTEMS of the WORLD. The COPERNICAN or SOLAR SYSTEM proved to be the only true one. The same explained at large. The Disposition, Number, Magnitudes, Motion, and Distances, of the HEAVENLY BODIES. The Nature of DAY and NIGHT; the Vicissitude of the SEASONS; the Nature of ECLIPSES; the Theory of COMETS; all illustrated by a curious ORRERY, PLANETARIUM, and COMETARIUM.

1. **T**HE Subject of this Section will be to explain the *true System of the World*, as it has been lately discover'd and demonstrated by the great Sir ISAAC NEWTON. By the *System of the World* is meant the Number, Disposition, and Order of the Heavenly Bodies, both among themselves, and with Respect to *one central Body*, about which the Motions of the Others are perform'd, and by whose Power and Influence they are govern'd and regulated.

2. The

2. The great Question in all Ages has been, *whether the Earth or the Sun be the Center of the planetary Motions*; the Vulgar and illiterate Part of Mankind declare for the Former; But all the skilful and learned not only assert the Latter, but can easily prove and demonstrate the same. Our *Senses*, indeed, represent the *Earth* the largest of all Bodies, and at Rest; and the Heavenly Bodies small, and in Motion about it. But Reason, Learning, and Experience all teach us the Contrary; and at the same time shew us that nothing can be more falacious than our common Sensations of Motion, Magnitude, and Distances of Bodies.

3. This vulgar Hypothesis *of the Earth's being the Center of the System* was taught in former Times by an *Egyptian* Philosopher named *Ptolomy*, and from him it is called the *Ptolomaic System*. That which asserts the Sun to be the Center is for that Reason called the *Solar System*; and because it was first taught by the School of *Pythagoras*, and when lost for many Ages, was at last revived by *Copernicus*; and last of all demonstrated and accounted for by Sir *Isaac Newton*; it has been also called, the *Pythagorean*, *Copernican*, and *Newtonian System of the World*.

4. The Indolence and Inattention of People are generally the Cause of their Ignorance; and they who will not make Use of their

Senses to discover the *Figure of the Earth* are not much to be depended upon for the *Rationale of a Planetary System*. But to leave Reflections, and come to Facts, I have contrived a Machine which I call a *Planetarium*, or Manual Orrery, that will at once represent both the *Ptolomaic* and *Newtonian System*, and fully and equally shew the *Falsity of the one*, and the *Truth of the other*.

Fig. 1.

5. In Order to this the *Ptolomaic System* is represented having the Earth in the Center immoveable, about which, when the Winch is turning, you see the several Heavenly Bodies move in the following Order, viz. *Mercury, Venus, the Sun, Mars, Jupiter, and Saturn*; just as shewn in the *Scheme*. Now in this Disposition of the Planetary Bodies, several things offer themselves at first Sight quite opposite to the true and real *Phænomena* of the celestial Motions, some of which I shall here specify, which will indubitably prove the Absurdity and Falsity of this *System*.

6. The first is, that by this Hypothesis, 'tis very evident that *Mercury* and *Venus* can never be seen from the Earth to go behind the Sun, because both their Orbits are contained wirhin that of the Sun; but in the Heavens we always see those Planets go just as often behind the Sun as before it.

7. Secondly, according to this Scheme, the Planets *Mercury* and *Venus*, like all the Rest,
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may be in *Conjunction* and *Opposition* to the Sun, or may be seen in any Position in the Heavens from the Sun. But this is quite contrary to Experience; no Man can ever see *Mercury* at more than about 21 Degrees from the Sun, and *Venus* never above 48, so far are they from being in Opposition or at the Distance of 180 Degrees from the Sun. *Venus* is the bright Evening Star, which every one knows was never seen in the *South*, much less in the *East*, at *Sun-Set*. And *Mercury* is so far from being seen in every Part of the Heavens, that he is very rarely ever seen by any Body.

8. *Thirdly*, in this *Vulgar System*, 'tis plain, since all the Planets are at an equal Distance in every Part of their Orbits, from the Earth; they would necessarily appear always of the same Magnitude: But this is contrary to Experience, for we see the Planets, especially *Mars*, perpetually altering their apparent Magnitudes, which prove they are not always at an equal Distance from us.

9. *Fourthly*, according to this Scheme, the Planets as they are always equally distant from the Earth, must always appear to move with *equable* or *uniform Velocities*, or never faster or slower at one Time than at another; which is directly contrary to what we observe in every Planet of the System.

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10. *Fifthly*,

10. *Fifthly*, If the common Hypothesis were true, we should see the Planets always move one Way, or in one Direction, *viz.* from *West to East*, but instead of that, we observe they sometimes move *forwards*, sometimes *backwards*, and sometimes *not at all*, but are *stationary* in the Heavens for many Days together. These Things with many more, which we must pass by, plainly prove such a System can have no Place in Nature, but is every Way repugnant to it, and therefore *false*.

11. But now if we restore the Sun to its rightful Place, the *Center of the System*; and the Earth to its proper Place among the Planets, and thereby represent the *Newtonian System* upon the same Machine, we shall see every Phenomenon of this System in the Planetarium, agree with those of the Heavenly Motions respectively; and not incumber'd with the least Difficulty or Absurdity.

12. Thus, first of all, we observe, according to this Disposition of the Planets about the Sun, that to a Spectator at the Earth the Planets *Mercury* and *Venus* will be seen to go both before and behind the Sun, or to have *two Conjunctions* with the Sun, but *no Opposition*; which are exactly their *Phænomena* in the Heavens.

13. *Secondly*, let S be the Center of the Sun; and from the Earth @ draw the right
Line

Line $\odot G$, $\odot H$ touching the Orbits of *Mercury* and *Venus* in the Points B and E; then *Fig. 2.* if *Mercury* be at B, and *Venus* at E, they will there appear at the greatest Distance from the Sun that is possible; and the Angle $S \odot B$, being the greatest Elongation of *Mercury* is not above 21 Degrees; and that of *Venus* $S \odot E$ is but about 47. And this is exactly agreeable to what we observe of their Distances in the Heavens.

14. *Thirdly*, In the *Newtonian System*, you observe all the Planets will have their Distances from the Earth perpetually varying; and consequently their apparent Magnitudes will be always variable also. And this we observe every Day in the Heavens; thus when *Mars* is nearest the Earth $\odot$ at M, he appears near as large as *Jupiter*; but when at his greatest Distance at R, you will scarcely discern him from a *fix'd Star*, but by his red Aspect. * The Surfaces of all Bodies decreasing as the Squares of the Distances increase. Now $\odot M$ is to $\odot R$ as 1 to 5; therefore the apparent Magnitude of *Mars* is 25 Times greater at M than R.

125^2
80
 $-45/125$

15. *Fourthly*, In this Scheme as the Earth $\odot$ is not in the Center of the Planetary Motions, their *true Motions and Directions* cannot be seen by us, but only their *apparent Ones*; and these are often contrary to the other. Thus, for Instance, while the Planet *Venus* is moving from F towards E, it

will appear to a Spectator at the Earth $\odot$ to move the same Way that it really does move, viz. *from West to East*; but while it moves from E to D it will appear to go backwards, *from East to West*. And thus in the Heavens, after *Venus* has gone forwards from the Sun to its greatest Elongation, we always see it return again with a retrograde Motion to the Sun; and the same is observed of *Mercury*, and of all the other Planets.

16. *Fifthly*, In this System, 'tis evident, the Planets must appear to move with *very unequal Velocities*; for since the Velocity is in itself uniform, and since it appears to describe the same Arch in the Heaven's in passing from F to E, as it does in passing from E to D, and E F is much larger than E D, therefore the apparent Velocity of its retrograde Motion thro' E D must be much greater than that of its direct Motion thro' F E. And thus the Motions of these Planets always appear to us in the Heavens.

17. *Sixthly*, At the Points E and B the Planets will appear to be *Stationary*, or not to move at all for some Time, because the Direction of their Motion in those Points, for some little Distance on each Side, coincides with the right Line $\odot$ E and $\odot$ B, which touch the Orbits. And agreeable hereto, we find the Planets in the Heavens
always

always *Stationary* at their greatest Elongation from the Sun.

18. *Seventhly*, According to this System, if the Earth has a Motion about the Sun in its Orbit then the Time between any two Conjunctions of the same Kind in *Venus* or *Mercury*, must be longer than it would be if ~~they were~~^{it was} at Rest, for in the latter Case, that Time would be equal to the *periodical Time* of the Planet's Revolution; but as the Earth moves as well as the Planet, that Time must be greater than the Planet's *Period*. For suppose while that Planet performs its Period the Earth moves on from $\odot$, then after *Venus* has returned to D, it must go on still farther, suppose to L, before it comes again between the Sun and the Earth now at K. And this we always find to be the Case by Observation; which therefore plainly proves the *Motion of the Earth about the Sun*.

19. Since then this System, and this only, is every Way consistent with the Phænomena of the heavenly Motions, and by which they can be rationally accounted for; it follows, that this only can be the *true System of the World*. And indeed it is not only plainly demonstrable by the foregoing Observations, but it is supported by the highest Reason. For since the Planets revolve in circular Orbits about a central Body, they must be constantly deflected from their right.

right-line Direction by a *centripetal Force* exerted upon them by this *central Body*.* And as this *attracting Force* is well known to be proportional to the Quantity of Matter, 'tis evident, the Quantity of Matter in the central Body ought vastly to exceed the Quantity of Matter in any Body whose Motion it controuls and governs. And therefore the *Sun only*, whose Matter is many thousand Times greater than that of all the Planets together, must necessarily be appointed for this Purpose; and not our *inconsiderable Globe of Earth*, which is *near a Million of Times less than the Sun*, and vastly less than *Jupiter or Saturn*.

20. Again 'tis extremely absurd on another Account to suppose any other Body but the Sun should be the *Center of the System*; for the Sun only is the Origin and Fountain of Light, and therefore that this might be equally dispensed to the whole System, and at all Times uniformly, to enlighten, and animate the several habitable Globes 'twas absolutely necessary to assign the Sun a *central Situation*, since no other could possibly answer that End; for were he placed between *Venus and Mars*, as in the Ptolomaic Scheme, those Planets would be scorched with Heat at his nearest Approach, and be congealed to Stone at his greatest Retreat. And such would be the wretched State of the other Planets, in a great Measure.

21. This

21. This *System*, therefore, as it is so noble a Work of Creation, and displays so much of the infinite Wisdom and Power of God, deserves a particular Description. Accordingly I shall give a summary Account of the several Bodies of which it consists, and the most remarkable Affections and Particulars relating to each.

22. The SUN is the central Body, and for that Purpose is the largest of all ; so very great is his Bulk, that his Diameter is computed to be 822148 Miles, viz. 100 Times greater than that of our Earth, and therefore his Bulk a Million of Times greater than the Earth. The Surface of the Sun when view'd thro' a Telescope, or in a dark Room, exhibits the Appearance of *dark Spots* of different Forms and variable in Number, but always uniform in their Motion over the Sun's Disk, which plainly proves the Motion of the Sun about its Axis in 26 Days nearly. What these Spots may be has not been yet discover'd.

23. The first Planet in the System is *Fig. 3.* MERCURY γ , 2460 Miles in Diameter; and at the Distance of 32 Millions of Miles, revolves about the Sun in 88 Days; this Planet is the least of all, and so near the Sun, that it is seldom visible to us, and we know but very little of it.

24. VENUS ♀ is the second Planet, which at the Distance of 59 Million of Miles revolves about

about the Sun in the Space of $224 \frac{3}{4}$ Days ; it is near the same Bigness with the Earth, being 7906 Miles in Diameter. This Planet has a Motion about its Axis in 23 Days, determin'd by the Appearance of a Spot on its Surface. Tho' it be a most splendid and glorious *Evening and Morning Star*, yet then in its greatest Lustre, not half its Surface towards us is enlightened ; but when viewed thro' a Telescope it appears horned like the Moon at 4 or 5 Days old.

25. The EARTH Θ , or terraqueous Globe, on which we live, is the third Planet in order from the Sun ; and is at the Distance of between 81 and 82 Million of Miles from it ; its periodical Time, or Revolution about the Sun is in $365 \frac{1}{4}$ Days, and about its own Axis it revolves in 1 Day or 24 Hours. It is 7960 Miles in Diameter ; and about 25 thousand in Circumference. It is the first Planet in the Heavens that is attended with a *Moon* or *Satellite*, of which more hereafter.

26. MARS δ the fourth Planet, at the Distance of 123 Millions revolves about the Sun in 687 Days. It is less than either the Earth or *Venus*, being no more than about 4444 Miles in Diameter. It has always a red or fiery Aspect ; has no Moon attending it, nor any Thing else remarkable about it.

27. But JUPITER μ , the 5th Planet is the most considerable of all, especially in regard
of

of his Bulk, as being no less than 81,000 Miles in Diameter; and therefore his Body or Globe *a thousand Times greater than that of the Earth*. The Distance of *Jupiter* from the Sun is 424 Millions of Miles, and it revolves about the Sun in $4332\frac{1}{2}$ Days or almost 12 Years. It is attended with 4 *Moons*; and with a good Telescope, it appears to have some *cloudy Streaks* or *Belts* crossing its Disk, but what they are is not known.

28. The most remote Planet of the System is SATURN ♄ , at no less than 777 Millions of Miles; it revolves about the Sun in $10759\frac{1}{4}$ Days, or in nearly 29 Years; and its Bulk is not very inconsiderable, being about 68,000 Miles in Diameter. It is attended with 5 *Moons*, and besides them it has a very *large Ring* encompassing its Body at the Distance of 20,000 Miles, which is also the Breadth of the *Ring*; but what this wondrous Phænomenon is, has not as yet been discovered.

29. The Moon which belongs to our Earth is at the Distance of about 240,000 Miles; and revolves in the Space of 27 Days, 7 Hours, and 43 Minutes. This is call'd the *periodical Month*; but the Time which passes between *two new Moons* is 29 D. 12. H. 44', and is call'd a *Synodical Month*; for the Reason of which Difference see *Art.* 18. The Diameter of the Moon

Moon is about 2175 Miles; the Moon is therefore about 50 Times less than the Earth.

30. The Reason why the *Moon always shews the same Face to the Earth*, is, because it turns round its own Axis in the same Time, that it revolves about the Earth. And the Reason of its doing this, is, because the *Earth's attracting Power* governs not only the *Motion*, but also the *Position* of the Moon; for as it acts always uniformly, so whatever Part of the Moon did at first turn towards the Earth, it must always keep towards it of Course; and the Manner how this is done, I shew by a new Contrivance in the *Planetarium*.

31. The *Motion* of the Moon about the Earth is extremely irregular, * which I have elsewhere accounted for. The *Phases* of the Moon are all exhibited, and the Reason of them clearly seen while the Moon revolves about the Earth in the *Orrery*. The Surface of the Moon appears thro' the Telescope very uneven, being in some Parts so vastly mountainous, * that some of the Hills are at least 9 Miles high, and the Vales, or rather Pits so large, as to be 2 or 300 Miles over, and as many deep. There appears nothing like an *Atmosphere* about the Moon, nor *Clouds*, nor consequently have they any kind of *Meteors*; and therefore the *Inhabitants of*
the

the Moon must be quite of a different Nature from *us*.

32. As to Eclipses, they happen in the Sun only, by the *Moon's* intervening between it and the *Earth*, by which Means the Shadow of the Moon falls upon the Earth when the Latitude of the Moon does not prevent it, by elevating the Moon above, or depressing it below the Earth, in or near the Time, when it is new; for then only can an Eclipse of the Sun happen. The Shadow of the Moon is of two Sorts, *viz. Total or Partial*; whoever lives on that Part of the Earth's Surface, where the total or dark Shadow falls, sees the Sun *totally eclipsed*; those in the *partial Shadow* or *Penumbra*, see the Sun eclipsed in Part only.

33. On the other Hand, an Eclipse of the Moon can only happen, when *the Earth* is *interposed* between the Sun and it; for then, if the Latitude of the Moon does not prevent, the Shadow of the Earth may fall on the Moon, and thereby cause either a *partial or total Eclipse*; and consequently these *lunar Eclipses* can happen only at, or near the Time of the *full Moon*. And indeed, if the Plane of the Moon's Orbit was coincident with the Plane of the Earth's Orbit, there would be always a *solar Eclipse* at the *new Moon*, and a *lunar Eclipse* at the *full*. The Manner how all this

this Affair of Eclipses is occasioned, will appear very plainly in the Machine.

34. The next Planet to our Earth which we find attended with Moons, is *Jupiter*; there have been 4 discovered, and may be easily seen thro' the Telescope in a clear Night; their Distances from *Jupiter* estimated in Semidiameters of *Jupiter's* Body, and the Times in which they revolve, are as follow.

Satellite	Semid.	Days	H.	'.
1	5 $\frac{6}{10}$	1	: 18	: 27
2	9	3	: 13	: 13
3	14 $\frac{3}{10}$	7	: 3	: 42
4	25 $\frac{5}{10}$	16	: 16	: 32

35. In *Saturn*, besides his Ring, we discover 5 Moons or Satellites revolving about him, whose Distances, estimated in Semidiameters of his Ring, and the Times of their Revolutions, are as follow.

Satellite	Semid.	Days.	H.	'.
1	2 nearly	1	: 21	: 18
2	2 $\frac{4}{10}$	2	: 17	: 41
3	3 $\frac{2}{3}$	4	: 12	: 25
4	8	15	: 22	: 41
5	23 $\frac{3}{10}$	79	: 7	: 16

36 These Moons of *Saturn* being so very remote from us, cannot be seen, but by

by a very good Telescope, tho' the Ring may; the Moons, either of *Jupiter* or *Saturn* appear only as small Stars, and nearly in a right Line, because the Planes of their Orbits are nearly the same, and parallel to the Plane of the Earth's Orbit. As these Moons may be sometimes in the Shadow of their Primaries, sometimes behind and before them, and sometimes one may intercept the View of another, it must happen that we can very rarely see them all together.

37. Such are the primary and secondary Planets, which compose our System. Of the Comets I shall speak by and by. Of all the primary Planets we know but little, excepting the *Earth* on which we live. And here we shall find several capital *Phænomena* which command our Attention, and can only be explained (so as to be clearly and rationally understood) by the *Orrery* and *Planetarium*; in which Machines *four* Motions of the Earth will be exhibited, *viz.*

1. The *annual Motion* about the Sun.
2. The *diurnal Motion* about its own Axis.
3. The Motion about the common Center of Gravity between it and the Moon.
4. The Motion about the *Axis of the Ecliptic*. Of which in Order.

38. As by the *Day* we mean nothing but the *Presence of the Sun*, and by *Night*, his *Absence*; so the general *Cause* of Day and Night, is nothing more than the Sun's shi-

ning on the Globe of Earth, by which Means one Hemisphere is enlightened, and the other dark; and as the Earth revolves upon its Axis once in 24 Hours, it must cause every Part on the Surface to pass thro' both the enlightened and dark Hemisphere in that Time, and so must necessarily produce an *Alternation of Day and Night* to every Place. And if the Circle, which bounds the light and dark Hemisphere, pass through the Poles of the Earth, it must occasion the Day and Night to be of an equal Length.

39. If the Axis of the Earth were always perpendicular to the Plane of its annual Motion, then would the Sun appear always in the Equator, and therefore equally distant from all Parts of the Earth on each Side under equal Latitudes; and consequently there must be in every Latitude one and the same Season of the Year perpetually.

40. But if the Earth's Axis be inclined to the Plane of its Motion, and be kept always in a Position parallel to itself, while it revolves about the Sun, then in this Case one End of the Axis will, in one Position be inclined to the Sun, and the other will be turned from it; the former will be included in the enlightened Hemisphere, the latter in the dark one. And the Earth revolving about its Axis, will occasion every
Part

Part about the Pole in the enlightned Hemisphere to describe a larger Part of its Circle in the light; than in the dark Hemisphere; and consequently will *make the Day longer than the Night* in all those Places. And just the contrary will happen with Respect to the Parts about the other Pole, or Extremity of the Earth's Axis.

41. To illustrate this Matter, let S be ^{Fig. 4.} the Sun illuminating the Earth in three different Positions in its Orbit, denoted by 1, 2, 3. Let CB be perpendicular to the Plane of the Earth's Motion, and let the Axis of the Earth NS be inclined thereto in an Angle $\text{NAC} = 23^{\circ} 29'$, and be always in a parallel Position. Then it is evident, that the North Pole N, and all about it from N to C, or $23^{\circ} : 29'$, will be in the enlightned Hemisphere CEB in the 3d Position. And the South Pole S, and the Parts about it to be, will be in the dark Hemisphere, just the contrary, of all which you observe in the 1st Position. But in the 2d Position, as the Circle which bounds the Light and dark Hemispheres, passes thro' both the Poles N, S, it will cause that the Parts about each of them will be equally enlightened.

42. Hence every Part in all the Northern Hemisphere ENQ, being turn'd to the Sun in the 3d Position, will have the Days longer than the Nights; thus suppose DH

H 2

be

be the Semicircle, which the City of *London* describes by the Earth's diurnal Rotation between Noon at D, and Midnight at H, it is plain the Length of the Day represented by D G is much longer than that of the Night G H; and it is as evident that the Night will be longer than the Day to all Places in the opposite or Southern Hemisphere E S Q in the Position of the Earth.

43. Again the Earth in the 1st Position will have all the Northern Hemisphere E N Q turn'd from the Sun; and the North Pole N, and all about it to C, for $23^{\circ} : 29'$, wholly in the dark; and every Place, as *London* in the Parallel D H will have the Night D G much longer than the Day G H; and the same Arch that measures the Length of Day and Night in one Position, measures the Night and Day in the other. The Southern Hemisphere E S Q is turned to the Sun, and every Place therein has the Day longer than the Night.

44. In the 2d Position the Circle bounding Light and Darkness passes through both the Poles, and must thereby necessarily make *Day and Night equal* in every Place on the Globe. This can happen but twice in the Year, and those two Days are called the *Equinoxes*, viz. the 21st of *March*, and 23d of *September*. Thus all the Variety that happens with Respect to Day and Night,

Night, will be clearly seen, and most easily apprehended from the Motions of the Earth in the Orrery.

45. To the same Cause also, *viz.* the oblique Position of the Earth's Axis NS to the Axis of the Ecliptic CB, we owe all the agreeable Alternations and Vicissitudes of the Seasons. For in the 3d Position as all the northern Hemisphere is turn'd to the Sun, we may observe; 1. That the Sun-Beams fall more directly upon it; and therefore strike with a greater Force. 2. A greater Number of Rays will fall on a given Space; and therefore the Heat will be the greater. 3. The Rays in this Case pass thro' a less Quantity of the Atmosphere, and so their Action will be more intense. 4. The Sun's Presence exceeds his Absence; and therefore the Light and Heat of the Sun will on all these Accounts make this the most *lightsome* and hottest Season of the Year, and what we call SUMMER.

46. On the other Hand, in the lower Part of the Earth, all about the Southern Pole to the Antarctic Circle B, is in the dark Hemisphere; the Sun-Beams are very weak, and of short Continuance, in the Southern Hemisphere ESQ, and there make the cold and dreary Season we call WINTER.

47. In the first Position, every Thing is just the reverse; in all the Northern Latitude from Q to N it is *Winter*; and in all
the

the Southern from Q to S, it is *Summer*, for the Reasons above assigned. And since in the 2d Position the Sun enlightens the Globe from Pole to Pole exactly, the Heat must necessarily be there in a mean Degree, and make the Middle of the *Seasons* we call SPRING, and AUTUMN. All which is very clearly explain'd and illustrated in the *Orrery* and *Planetarium*.

x 48. Besides the annual and diurnal Motions of the Earth, there is another, which is a conical Motion of the Earth's Axis, by which the Poles of the Earth revolve about the Poles of the Ecliptic in a *retrograde* Manner, and so very slowly as to amount to no more than *one Degree* in 72 Years, or one Revolution in near 2600 Years. And therefore in the Space of a few Years it is altogether imperceptible.

49. Yet as in a long Course of Time, it becomes very sensible, and induces very considerable and momentous Alterations and Changes in the present (and seemingly constant) State of Nature: I shall contrive by a new *Diagram* to represent it very plainly, tho' it cannot be so compleatly conceived as by seeing it actually perform'd in the *Planetarium*. Let ENQS be the Earth; EQ, the Equator; NS the Axis of the Earth making an Angle NCP of $23\frac{1}{2}$ with the Axis PL of the Ecliptic; TR is the Tropic of Cancer, BD that of Capricorn;

Fig. 5.

corn ; and *Pr*, *b* *L*, the two polar Circles in the present Position of the Earth's Axis.

50. Now the Earth's Axis *N S* is always in Motion upon the Center *C*, moving backwards in such Manner as to describe the Surface of a Cone *N C n*, in the doing of which, it will by its Direction continued to the Stars, describe among them the Circle *W X Y Z*, whose Diameter is 47 Degrees of a great Circle. In Consequence of this, the Star *W*, which is at present nearly over the North Pole *N*, will be in Time deserted by the Pole *N*, which by this conical Motion will be carried backwards, and after about 6500 Years it will be directed to a Star *X*, which is now in the East, and this will then be our North Star.

51. After this in 6500 Years more, the Axis of the Earth will get into the Situation *n s*, and point to the Heavens, at *Y*, which will then be the North Pole, 47 Degrees from the present North Pole at *W*; and $8\frac{1}{2}$ Degrees South of the Zenith of *London*, whose Parallel, or Path is *G H*. After this it will recede in the same Time to *Z*, in the present western Part of the Heavens, and nearly there it was at the Creation, or about 6000 Years ago; since which Time it has crept backward to *W*, where it now is.

52. By this Motion of the Earth, as each Part of its Surface is slowly turned about backward from East to West, the Stars will

Being, does not the Vibratory Motion of the Axis & the Stars with the Polar Motion. H 4

all seem to move forwards from West to East in the same Time ; and hence it is that they are constantly changing their *Longitude* in the *Ecliptic*, and *Declination* from the *Equator*. And thus the Constellation which was formerly in *Aries* is now in *Taurus*; that of *Taurus* is now in *Gemini*; and so of the Rest.

53. Hence also it is, that as the equinoctial and solstitial Points are carried backwards, the Sun will arrive to them each Year sooner than if they were at rest, and consequently make what we call the *Precession of the Equinoxes*; because the Time of the *Equinoxes* each Year will *precede* the Time in which it happened the Year before.

54. Hence all the Seasons of the Year will have a retrograde Motion thro' all the Months of the Calendar; and it is easy to see from the Figure, that there is in the Space of 13000 Years so different a Position of the Circles of the Sphere with Respect to the *Ecliptic*, that in the present Position the *Tropic of Cancer* T R touches the *Tropic of Capricorn* b d at the End of that Period; whence it appears the Sun is now in that Part of the *Ecliptic* on the longest Day, where it will then be on the shortest, and - *vice versa*.

55. The Cause of this Motion of the Earth * Sir *Isaac Newton* has shewn to arise from the Figure of the Earth not being *spherical* or *truly globular*, but of an *oblate Form*, having the Diameter E Q of the Equator longer than the Axis N S by about 80 or 90 Miles. * Also that this was owing to the *centrifugal Force* (arising from the diurnal Rotation) being much greater in Parts near the Equator than in those towards the Poles.

56. We come now to contemplate the Motion of COMETS, which make a very wonderful Part of the *Solar System*. These are a Sort of Planets, quite different from those we have been speaking of, as they are capable of sustaining the *greatest Alternations* of Heat and Cold, and revolving about the Sun in very *eccentric Orbits*. They appear surrounded with a large and dense Atmosphere, which when near the Sun becomes greatly heated, raised and expanded into a surprizing large and fiery Vapour, or Tail, which makes it appear a *blazing Star*.

57. With Respect to the Cause and Manner of a Comet's Motion, we are to observe that tho' the Form of its Orbit be very elliptical, yet the Motion in that Ellipsis is the Result of two Forces acting upon the
Comet

Comet (as well as in the Case of a Planet) *viz.* One a *projectile Force*, which would, alone carry it from the Sun in a right Line; and a *centripetal Force* (or Gravity) by which alone, it would be carried directly to the Sun. Now in the Case of a Comet both these are so compounded together as to make it describe an Orbit more or less *Elliptical* about the Sun, or Center of Force.

Fig. 6.

58. But to be more particular, let AFPC be the Elliptic Orbit of the Comet C, C T its Tail; A its *Aphelion* or greatest Distance, and P its *Perihelion* or least Distance, from the Sun S. * Now the Power of Gravity upon the Comet every where decreases as the Squares of the Distances increase. So that if SA be 10 times SP, the Gravity at P will be 100 Times greater than at A; and therefore the Velocity of the Comet at P, and in all Parts about the Sun, is vastly greater than in the remote Parts of the Orbit, and at A where it moves slowest of all.

59. * If we suppose the Comet describes the Arches PB, BD, DE, in the same or equal Times, then will the Areas PSB, BSD, DSE be equal to each other; which is the constant Law of all the planetary Motions. The Reason why the Comet does not go quite away from the Sun at A is because

cause the Force by which it goes off from the Sun, decreases, in receding from the Sun in a much greater Proportion than Gravity by which it is therefore made to turn round at A, and again to approach the Sun. And at P, the same Force prevails over the Force of Gravity, and prevents its falling into the Sun, by whirling it swiftly round in that Part.

*And it is by
girds it in a
of velocity.*

60. There have been a great Number of Comets observed from Time to Time, but though it be sufficiently discovered that they move about the Sun in the Manner above explain'd; yet scarcely any of them have been observed to return often; and only one so often as to have the periodical Time of Revolution and Form of its Orbit determin'd with Certainty. This Comet has appeared five several Times, at the Interval of $75 \frac{1}{2}$ Years; and the last Time it appeared was *An. Dom.* 1682; and therefore we certainly expect it again in the latter End of the Year 1757. All these Particulars of a Comet's Motion are represented to the Eye by the *Cometarium*, and exemplified at large in the Comet last mentioned. Also by a new Construction and Elevation of the Plane of cometary Orbits in general, and especially of that of the Year 1743, by which it will appear how enormously large their Tails are; and by what a signal Providence we are constantly

stantly preserved from the destructive Shock of those flaming Vapours, when they transit the Earth's Orbit with a stupendious Velocity.



SECTION



The Nature of FLUIDITY and Fluid Bodies explained; The Hydrostatic Paradox; The Nature of Sinking and Swimming; The Specific Gravities of Bodies by the HYDROSTATIC BALLANCE; the Use of the HYDROMETER; Of AQUADUCTS and FOUNTAINS; The Theory of Pump-work; Several curious Sorts of PUMPS; The Theory of the TIDES; Newsham's WATER-ENGINE, &c.

I. **T**HIS Section is intended to explain and illustrate that Part of Natural Philosophy, which is called HYDROSTATICS; and which treats of the Nature and Action of *Fluid Bodies*; and the Construction and Rationale of such Instruments and Machines as depend upon their peculiar Properties. The Definition of a Fluid is — *A Body, whose Parts move freely among themselves, and therefore yield to the least Force that is impressed upon them, more on one Part than another; for if the Force be uniformly exerted over all the Surface, no Particle can possibly move.*

2. The

2. The Reason of this Definition is derived from the Nature of the Thing: for it has been shewn in the first Section, that the Power of Cohesion unites and binds the Parts of Matter together with various Degrees of Force, in Proportion as they touch by a greater or less Quantity of Surface; and consequently those which touch by the least Number of Points, must be most free to move among themselves by any Force impressed, and therefore must constitute a fluid Body in the most perfect Degree.

3. In order that the Particles of Matter may touch by the least Quantity of Surface possible, * *their Figure must be perfectly round or spherical.* Hence it follows that since even in spherical Particles there will be a small Degree of Contact, and consequently of Cohesion or Tenacity, there is no Body in Nature *absolutely fluid*; unless it can be shewn, that the Particles of some fluid Bodies do not actually touch each other; and indeed there are not wanting Experiments which seem to favour such a Conclusion.

4. However that Matter may be, we have Bodies so far fluid as to acquire by that Means some very peculiar wonderful and useful Properties, and a Manner of Acting quite different from *solid Bodies*. Indeed both solid and fluid Bodies act only by Pressure arising from the Gravity of their Parts; but then in Solids, this Action or Pressure

is only in *one Direction, viz. perpendicularly downwards*; and in *Proportion to the Quantity of Matter*. Whereas Fluids press not in one only, but in *every Direction upwards, downwards, and sideways, equally*; and that with a *Force not proportional to the Matter, but to the Height of the Fluid*.

5. The natural Reason of this is evident; for since every Particle is quite free to move, and all press each other on every Side and in all Directions, it is plain, if any one Particle or more, were pressed on one Part more than another, they would instantly move, and continue their Motion till such Time as they acquired a Situation, where the Pressure is on every Side equal; and in that Case only the Body of the Fluid could attain its *natural State of Rest*.

6. That the Pressure of Fluids is every Way and in all Directions equal, may and will be shewn by divers Experiments in the Sequel of this Section. There is no Need of an Experiment to prove the Pressure of *Fig. 1.* Fluids downwards. But their *Pressure upwards* is a Matter not so well known or easy to be conceived; and therefore I shall make it plain and evident by the following Experiment. ABC is a tall Tube fill'd with Water near the Top, into which a small Tube DC is immersed with its open End C downwards, the other End D being hermetically seal'd.

7. In

7. In the lesser Tube, the Water is seen to rise to the Height CE, which directly demonstrates a perpendicular Pressure of the Water upwards in the Tube; because as the Tube is full of Air when immersed, and the Air is a springy Body, it would by Virtue of its Spring resist the Water and prevent its Entrance into the Tube, were it not that the Water presses against the Air with a greater Force, and by that means causes the Air to retreat from the Orifice up into the Tube so far that its Density makes its Spring equal to the Force of Pressure in the Water, and then it can rise no higher.

8. That this Pressure upwards at the Point C is equal to the Pressure downwards at the same Place will be shown farther on. And since, there is known to be a Pressure upwards and downwards equally in every Part, and also that the Force with which fluid Particles press, or are pressed, is on every Part equally the same (*Art. 4, 5.*) it follows, that there is a Pressure in Fluids *laterally* or sideways, and every Way *equal to the Gravity*, and proportional to the *Height of the Fluid*.

9. But what is still more wonderful, and deservedly called the *Hydrostatic Paradox*, is, that this Pressure of Fluids is proportional to the Height of the Fluid only, without any Regard to the Quantity thereof; or, in other Words, while the Base or Bottom on which the

the

the Fluid presses remains the same, if the Height of the Fluid be encreased, the Pressure on the Bottom shall be increased in the same Proportion, tho' the Quantity of the Fluid be the same all the while. And this is clearly evinc'd by the following Experiment.

10. Let $A B C D$ be a hollow Cylinder of Brass, Glass, &c. within which a Bladder *Fig. 2.* containing Water is freely suspended by a Brass Top at $A B$, and having a Brass Bottom $a b G$; in the Middle of which at G , is screw'd a long Brass Wire $G H$ hanging to the Hook of a Steel-Yard at H ; about this Wire is screw'd the tall Glass Tube $E F$ in the Center of the Top $A B$: When this Wire is disengaged from the Steel-Yard, the Bottom of the Bladder is in its lowest Situation $c d$, and the Water is just seen in the Tube at E . Suppose now the whole Quantity of Water $A c d B$ were a Pint, or one Pound.

11. Then upon hanging the Wire $G H$ on to one Part of the Steel-Yard, and a Pound Weight on to the other, it is evident that Weight, by means of the Wire, will act upon the Brass Bottom $a b$, in a Direction quite contrary to that of the Pressure of the Water; and consequently; wherever the Bottom $a b$ is at Rest, there will be an Equilibrium or Equality of Force between the Action of the Weight and the Gravity of the

I Water

Water upon it ; and so the Pressure of the Water will be always expressed in *Pound Weights*. Thus, suppose the Pound Weight were placed on the first Division of the Steel-Yard, as the Water is also one Pound by Supposition, 'tis plain the Bottom will retain its Situation *c d*, and the Water will not be sensibly moved upwards. But upon moving the Pound Weight to the second Division of the Steel-Yard, it will act upon the Bottom with the Force of two Pound, and therefore since the Water acts upon it with the Force of but one Pound, it follows, that the Bottom will be drawn up, and the Water will rise in the Tube to a Height which is such, that a Cylinder of Water of that Height, and of the same Base *ab*, will weigh just one Pound. The same Quantity of Water, therefore, now presses the Bottom with double the Force as at first.

12. If the Pound Weight be removed successively to the 3d, 4th, 5th, 6th, &c. Divisions of the Steel-Yard, the Bottom will be drawn upwards with Forces which will be as 3, 4, 5, 6, &c. Pound ; and therefore the Water will rise in the Tube to the Heights *E 2*, *E 3*, *E 4*, *E 5*, *E 6*, &c. whence it appears, that the Force or Pressure of Fluids is every where proportionable to the Altitude of the Fluid ; and to that alone, which was to be proved.

13. The natural Reason of this wonderful Phænomenon of Fluids is this, *viz.* That since the Pressure of Fluids upwards at the same Depth below the Surface, is the same as downwards (*Art 6, 7.*) the Water will every where press upwards against the fixed Top of the Vessel A B, and upon the whole with a Force equal to the Weight of a Cylinder of Water of the same Height of that in the Tube, and Base the same as A B, as is evident by the Experiment. Now since the Top A B is fixed, it will re-act upon the Water with just the same Force as the Water acts upon it, and so will, by this *Re-action*, supply the want of Weight of such a Cylinder of Water as abovemention'd. This Force of Re-action, then, joined with the Weight of the Water below A B, must necessarily be the same upon the moveable Bottom *a b*, as the Weight of a Cylinder of Water on the same Base and the Height of that in the Tube. *This Force of Re-action* will be fully explained in the next Section.

14. By the same Principle in Fluids, it is, *That a heavy Body immersed in them, always looses just so much of its Weight as is equal to the Weight of an equal Bulk of the Fluid.* For no Body can descend in a Fluid without raising an equal Bulk of that Fluid; and that equal Bulk of the Fluid will resist or re-act against the descending Body *with all its Force of Gravity*; and since *Action and Re-*
I 2
action

action are equal, (Sect. VI.) it follows, that just so much Gravity must be deducted from the Body immersed, and it will descend with the Remainder, or residual Gravity.

Fig. 3.

15. To shew this by Experiment, we have a solid Cylinder A B of Brass, which exactly fits the hollow cylindric Bucket C D, and suspended from the Bottom of it by the String E F; this Bucket and Solid are counterpoised very nicely in the Air by a Weight G on the Balance H I. While they are thus in Equilibrio, the Solid is immersed in the Water K L, upon which the Equilibrium is immediately destroyed, the Weight G preponderating very considerably. If now, Water be poured into the Bucket C D till it be full, the Equilibrium is restored again; and that by the *Addition of the Weight of an equal Bulk of Water*, which fully proves this most useful Proposition of Hydrostatics.

16. Hence it appears, that the true and absolute Weight of Bodies cannot be immediately known by the Balance, unless they could be weighed *in vacuo*; since when they are weighed in any *Medium*, as Air, Water, &c. we have only the Difference of the Weight of equal Bulks of the Body and the Medium. Hence we derive the Idea or Definition of *Specific Gravity*, which is a relative Term, and implies no more *than the*

the Gravity of one Body compared with that of another under equal Bulks. Thus if a Cubic Inch of Glais be three times heavier than a Cubic Inch of Water, its specific Gravity is said to be three times as great as that of Water.

17. To find how much heavier any Body is than Water, and consequently to determine the various specific Gravity of Bodies in general, we have the Invention of the HYDROSTATIC BALLANCE, the Reason of which will be quite evident from the foregoing Experiment (*Art. 15.*) and the Use of it extremely easy in the *new Method* I have contrived for that Purpose, and which I shall next exhibit and exemplify.

18. Let I K represent this Balance, and *Fig. 4.* its two scales H, F; to the Scale F I fix a *Horse-Hair* F G, with a Loop at the lower End G, by which a Body, as A B, may be very readily suspended. Suppose then A B were a Piece of *Brass*, whose specific Gravity is required to be found; proceed thus; Suspend it in the Horse-hair, and find its Weight in Air by Grain Weights put into the opposite Scale H, till there is a nice Equilibrium, then lifting the Body A B up, place under it a Glass of Water C D, in which let the Solid sink, and it will become lighter, and the Scale H will preponderate (*Art. 14.*) then let grain Weights be put into the other Scale F till the Equilibrium be re-

stored; these will express the Weight of a Bulk of Water equal to A B (*Art. 15.*) Now the Weights in H are to the Weights in F as the Weight of Brass to the Weight of Water under equal Bulks; and therefore *the specific Gravity of Brass is known.*

19. And it will always be found that the Weights in the Scale H will be to those in F as 8 to 1 nearly; and if the Solid A B were *Gold*, those Weights would be as $17\frac{1}{2}$ to 1; in *Silver* they are as about 10 to 1; in *Lead* as $11\frac{1}{3}$ to 1; and so a Table may be composed exhibiting the specific Gravities of as many Kind of Solids as you please.

20. And it is still more easy to find the specific Gravities of Fluids; for in this Case nothing more is necessary than first to equipoise any Solid A B in the Air, and then immerse it successively in as many different Sorts of Fluids as you will; and the Number of Grains put into the Scale F each time to restore the Equipoise, will represent the specific Gravities of those Fluids respectively, because they express their Weights severally under equal Bulks.

21. In this Way also one might find the specific Gravity of Quicksilver by immersing a Piece of Gold in it (for nothing but Gold is heavy enough to sink into it) but for Variety's Sake, I shall shew another Way of doing it. Let A B be a tall Glass Tube close at the Bottom, in which pour a little Mer-

cury to the Height D C. In this let a small Tube G B be placed, open at both Ends, and upon the Mercury pour Water till its Height C F be equal to 14 Inches; then will the Mercury be raised in the Tube B G to the Height C E equal to one Inch. Now since the Pressure or Gravity of Fluids is proportional to their Heights only (*Art. 9.*) and since there is an Equilibrium between one Inch of Mercury and 14 Inches of Water, it is plain *that Mercury is 14 times more dense, and therefore 14 times heavier than Water.*

22. The Use of this Experiment is very extensive, as we shall see farther on, and perhaps there is nothing that will afford a clearer Idea of the Reason of the Tides, or flowing and ebbing of the Sea. For supposing the Earth I F G H were wholly covered over with Water; and if this Water were affected by the Earth's Attraction only it would be every where of a spherical Figure *Fig. 6.* A B C D (by what was shewn in Sect. I. 8.) because every Particle being equally attracted there must be an equal and uniform Density and Gravity, and consequently an equal Height of the Water throughout the whole.

23. But supposing the Moon at M attracts the Waters at the same Time, this will be in a contrary Direction to that of the Earth in all the Hemisphere A B C next the Moon, and thereby the Gravity of the Waters will be diminished, and most of all those Parts

near the Moon. As the Waters then are thus made lighter about D than at A or C, there will be required a greater Altitude in those at D to maintain the Equilibrium with the heavier Water at A and C. The Waters therefore at D will rise from D to d ; and proportionally every where towards A and C.

24. In all the opposite Hemisphere A B C the Attraction of the Moon conspires with that of the Earth, and the Gravity of the Waters will always be proportional to the Sum of these Attractions, which will be least of all at B, as being most remote from the Moon; the Waters, therefore, at B will be lightest of all; and consequently must rise to a greater Height G b than any where else towards A and C.

25. As the Water rises about the Parts D and B, they must necessarily subside below the Circle in the Parts A and C to the lesser Heights F a , H c . As these Points A, B, C, D, are 90 Degrees distant, they must come to the Meridian at the Distance of 6 Hours in Time. If the Sun be in the same Part of the Heavens with the Moon, as when she is new, or in the opposite Part, as when she is full, the Waters in D and B will thereby be render'd yet lighter, and so will rise higher, and make what are called the *Spring Tides*. * The greatest Height d is not under the Moon, but follows her; * and D d is equal to twice A a .

26. If two Bodies of different Kinds of Matter, as Brass and Glass, be equipoised in the Air, and then weighed together in Water; the Equilibrium will be destroyed, and the Brass will preponderate, because its Bulk being less than that of the Glass, it will loose a less Part of its Weight, or be less resisted than the Glass, and therefore be heavier in the Water. (See *Art. 16.*) And this we confirm by Experiment.

27. Also from hence we see *the Reason in general why any Body sinks or swims in a Fluid.* For suppose any Body were heavier than Water in the Proportion of 8 to 1, as Brass then in the Water, it can lose but $\frac{1}{8}$ Part of its Weight (*Art. 14*) and therefore must descend with $\frac{7}{8}$ of the whole.

28. If a Body, as *Cork*, be lighter than Water in the Proportion of 1 to 4; then 'tis plain, as there is 4 times as much Weight in an equal Bulk of Water, such a Quantity cannot be raised by the *Cork*, and consequently it *cannot immerse itself, or sink in Water wholly*; but it will raise $\frac{1}{4}$ of its Bulk of Water, as being of equal Weight, and so will swim with $\frac{3}{4}$ Part of its Bulk in the Water.

29. If a Body be of the same specific Gravity with the Water, *it can neither sink nor swim.* For if it be immersed it must loose all its Weight (*Art. 14*), and so cannot descend. Also it will every where tend downwards with

with a Force equal to the Resistance or Pressure of the Water upwards; and *and so it will not rise to the Top or swim.* Hence appears the Reason, why a Bucket of Water, a Man, or any Animal in Water, seems so very light, and to have scarce any Weight at all. These Phænomena also are all illustrated by Experiment.

30. Hence the Reason also of another paradoxical Position is evident, *viz. The heaviest Body placed at a proper Depth in Water shall there be sustain'd by the Water, or kept from sinking tho' left freely to itself.* To prove this by Experiment, let $abcd$ be a Piece of Brass, which by means of a String is drawn tight against the Orifice of the Glass Tube $afgb$ (with a Piece of wet Leather at ab to keep out the Water) in this case it is plung'd more than 8 times its Thickness eb under Water in the Jar $ABCD$; and the String being there let go, the Brass does not descend or sink, but is sustain'd by the Water.

31. For the Pressure upwards against the Surface dc is equal to the Weight of a Column of Water $dhic$, whereas the Pressure downwards is equal only to the Weight of the Brass, or 8 times its Bulk of Water, eb , which, as it is less than the former, shews plainly enough that the Brass cannot sink at any Depth greater than 8 times its Thickness (see *Art. 18 and 19.*) In the same Manner
it

it is shewn by Experiment that a Piece of *Cork* will not rise or swim in *Mercury* if it be kept from pressing it upwards on its under Surface.

32. Hence also the Reason of another *Phænomenon*, which used to be thought strange, viz. *that the same Body shall sink in one Fluid and swim in another*. Thus, a Piece of Brass will sink in Water, but as readily swim in Quicksilver; because it is heavier than Water in Proportion of 8 to 1 (by *Art. 19.*) and lighter than Meruury in the Ratio of 14 to 8, (by *Art. 19 and 21.*)

33. Next to the *Hydrostatic Ballance*, there is no Instrument which owes its Invention to this Branch of Science more useful than the HYDROMETER or *Water-poise*; it consists of a large hollow Ball or Globe A B D, with a long Stem or Neck A F G; and a Weight at the Bottom B C E, to be screw'd on and off at pleasure, and such as shall be sufficient to sink the Instrument in any proposed Fluid, till its Surface shall coincide with the middle Point F in the Neck.

Fig. 8.

34. Suppose the Stem A G divided into 20 equal Parts; and the Weight C B so adjusted as to sink the Hydrometer in *Rain-Water* (which is the lightest of all Waters) to the middle Point F, then if it be immersed in any other Water, it will not descend so deep in it, by which means that Water will be found to be heavier. And thus

thus in general, all Kinds of medicinal Fluids, mineral and other Waters may be examined as to their Gravity or Density. Indeed an exact Estimate or Comparison of the respective Gravities of Fluids may be made by this Instrument, but that is better done by the Hydrostatical Ballance.

35. Again, the Strength of all spirituous Liquors may by this Instrument be very easily discovered and compared. Thus, if pure Spirit of Wine be poured to an equal Quantity of Water, it makes what we call *Proof-Spirit*; then if the Weight B C be such as will sink this Instrument in this Proof Spirit to the middle Point F, or 10th Division in the Stem; if you put it into any Spirits that is weaker, it will not sink so deep because of the larger Proportion of Water which is heavier than Spirit. On the other hand, if it be immersed in Spirits that are above Proof, it will sink deeper than the Point F; and so in all Cases it may be readily and certainly known, whether any Sort of Spirit be above or below Proof.

36. Another very curious Use of this Instrument is, *to find immediately if Money be good, or any ways debased or diminished.* To this End, instead of the Weight B C, I screw on a Piece so contrived as to have a Piece of Money affix'd to it instantly; and supposing that to be a *Guinea of George II.* the whole is so adjusted as to sink in common Water to the

the Point F ; but if a faulty Guinea be put on, no part of the Stem will be immersed, nor the upper Part of the Body ; whence the Fraud is easily discovered. And thus it may be accommodated to examine any other Species of Money. Nay, even all *Degrees of Difference in good Money*, as appears by the Experiment.

37. The Method of conveying Water by AQUEDUCTS, is the next Thing to be explained ; to represent this Affair ; let A B be a *Reservoir* of Water, its descending Pipe C D ; in the Part D there is a Piece F (with a Joint) screw'd on, which communicates the Water to the Tube G H affixed to it on the other Side. By means of the Joint at F, this Tube G H may be put into any Situation. Then supposing E K the *horizontal Line*, and A I parallel to it, you will find that in every Position of the Tube, the Water will constantly rise in it to the Level A I, and no higher. Fig. 9.

38. The Reason of this is evident ; because when a Flusd becomes divided into two Parts, and is at Rest, there must be an *Equilibrium of their Force or Pressure* against each other ; but this cannot be, but from an *equal perpendicular Altitude* in each Part above the Horizou E K (by *Art. 5 & 9.*) and consequently as the Height of the Water in the Reservoir is A E, that of the Water I K in the Tube G H, must always be equal to it;

it; and there its Surface in every Position of the Tube will ever be in the Line A I parallel to the Horizon E K.

39. If then G H represent the main Pipe which is laid up the Side of a Hill on which a Town is built, it is evident, that the Water will be conveyed from this Pipe by the lateral ones to all the Houses situated below the Level A I; but to none above it, from I to H.

Fig. 10 40. Let the Figure and Size of the Conduit-Pipe G H I be what it will, the Water will still rise in it to any Part G, or I below the Level of that in the Reservoir A B. And therefore Water may be conveyed over any high Place F G H, as a House, a Mountain &c. Or from the Top of one Hill G across the Vale H to the Top of another Hill I, by means only of a bended Pipe F G H I, Hence the vast and expensive Labour of building *Aqueducts from Mountain to Mountain* is not necessary, but where more Water is required than can be carried by Pipes.

Fig. 11 41. As the Tube contributes nothing towards the Cause of the Water's rising in it; so if the Tube were away, and a small Piece or Adjutage G were affixed to the Part F with a little Hole in the Top, the Water would rise thro' that Hole in the Form of a *Jet d'Eau* or *Fountain* G I, nearly to the Height of that in the *Reservoir* A B. But because there is some Cohesion in the Fluid,
some

some Attraction and Friction in passing thro' the Hole, a considerable Resistance from the Air, and the Weight of the Water above impeding the Ascent of that below, we find the Jet can never possibly rise to the full Height of the Reservoir which supplies it.

42. The Operation of the Syphon C F E is easily accounted for by the Pressure of Water in Conjunction with that of the Air. *Fig. 12*
For suppose the Syphon filled with Water, and inverted with its shorter End in a Glass of Water A B, then if there were no Pressure of Air to effect the Water, the Water in the Syphon would immediately separate in the highest Point F, and run down from thence in each Leg towards C and E, and so there could be no Operation at all.

43. But as there is a Pressure of Air constantly acting upon the Surface of the Water in A B, it will cause Water to rise from C to F; for since the Pressure of Air is the same on both Orifices C and E, and the Leg F E is the longest, there will be a greater Weight of Water at E than at C, and consequently the Water in the Leg F E will run out; and if we suppose the Mater to part at F, there must be a Vacuum in the Syphon at F, which is impossible while the Water at C and E is under the Pressure of the Atmosphere. It must therefore be always full till the Surface of the Water in the Jar comes to the Orifice C, and then no more can be pressed up;

'Tis

'Tis easy from what has been said to see, that if the external Leg were FD equal to FC , or if the two Orifices of the Syphon C, D , were in the same horizontal Line CD , the Water could not move thro' it.

Fig. 13.

44. Hence also the *Phænomenon* of the *Tantalus Cup* is easily understood, for if a Syphon be bent in the Form of a Handle CDE , and fixed into the Side of a Mug or Cup AB , so that the Orifice C may communicate with the Cup near the Bottom, and the Orifice E be a little below it; then, upon pouring Water into the Cup it will rise in the Handle at the same Time; and when in the Cup it comes to the Height F so as to be upon a Level with the highest Part D of the Handle, the Water will then descend thro' the other Part DE , and run out without ceasing at E , till the Water descends in the Cup to the Orifice C .

45. Hence we see the Reason why some Ponds and Wells loose or discharge all their Water in a surprising Manner as soon as they are fill'd, by some *analogous subterranean Duct or Syphon*. Also the Reason of *intermitting Springs*, which are supplied by a Syphon, and which can only run when that works. Also those called *reciprocating Springs*, as they are supplied by a constant Stream, cannot intermit; but if at the same time they receive Water from an *intermitting Syphon or Duct*, the Surface of
 3 their

their Waters will rise and fall in *correspondent Reciprocations*. Of all which we have an admirable Instance in that Spring called *Laywell* near *Brisham* in *Devon*, whose Water ebbs and flows just *ten Times* every Hour.

46. The *Antigugger* has sometimes its Uses, and therefore it is usual to shew it by Experiment: It consists of a small curved Tube, which is to be put into the Neck of a Bottle or Vial, that so while the Liquor is running out, the Air may enter thro' the Tube without rushing thro' the Body of the Liquor (which makes the usual *Guggling*) and thereby disturb the Sediment, and foul the Liquor.

47. We come now to the most useful Part of *Hydrostatics*, which concerns *Pump-Work*, and the Reason of the Operation of PUMPS in general, will be easy to understand from the foregoing Principles. A *Water-Pump* is every way like an *Air-Pump*, consisting of a Fig. 14. Barrel, a Piston, and two Valves; all which are here of the same Use as these, but made of different Materials. The Form of the common Pump is represented in the Figure in three Parts; the first is the Cistern A B, into which the Water is brought by the Piston K L, which plays in the second Part or Barrel D E; and the third Part is the Pipe or Tube F G, which goes down to the Water in the Well or Vessel H I.

48. In the Bottom of the Barrel there is a
K Hole,

Hole, over which is placed a *Leathern Valve* to move up and down ; and the same Sort of Valve there is in the Bucket L of the Piston, which has also a Perforation to let the Water pass thro' it. These Valves open upwards, and permit the Water to rise ; but prevent its return by shutting down close upon the Holes beneath. The Bucket L is lined with Leathers, to make it fit the Inside of the Barrel very nicely, that so none of the Water above may get into the Part below ; and to *fetch the Pump*, as they call it, or to make the Water rise, they first pour Water into the upper Part over the Bucket to make all tight.

49. Then the Piston, being supposed at the Bottom of the Barrel at E, is raised up from thence to Q by the Handle K M ; then is the Air contained in the Tube F G expanded into the large Space of the Barrel from E to Q and consequently has its Spring lessen'd ; it will therefore press with less Force on the Water contain'd within it, than the Air presses that without ; hence the Water must rise in the Tube to some Height O, till its Weight, and the Spring of the Air within, be equal to the Pressure of the Air without.

50. When the Piston is forced down, the Air beneath rises thro' the Bucket ; and that in the Pipe above O, when the Piston is raised, is expanded again into the Barrel ; and its Spring being again diminished, the Water will

will be raised to a great Height P in the Tube. And thus as the Air becomes gradually exhausted, the Water will rise higher and higher, 'till at last it will arrive to, and force up the Valve N in the Barrel; and having ascended thro' it, it cannot return, but must, upon the Descent of the Piston, be forced thro' its Valve also; and as this Valve also prevents its returning, it must be raised by the Ascent of the Piston. into the Cistern of the Pump A B, and there run out thro' the Spout C.

51. Any Pump of this Construction will raise Water to any Height not exceeding 32 or 33 Feet. For since the Water rises, and is sustained in the Pump by the *Pressure of the Air*, and since this Pressure is equal to the Weight of a Column of Mercury $29\frac{1}{2}$ Inches high (Sect. III. 31.) it will be equal to the Weight of a Column of Water 14 Times as high (*Art.* 21) therefore $29\frac{1}{2} \times 14$ makes 413 Inches or $34\frac{1}{2}$ Feet nearly, which is the Height to which the Water would rise in a Pump, if all the Air could be perfectly exhausted. But as no Pump of this Kind is or can be made so Air-tight as to do that, the Water never rises so high.

52. The Pipe should be of so large a Bore as to admit the Water into the Barrel so freely, as to follow the Piston without leaving any Space between; for unless the Water be in Contact with the Piston below there is much

more Force than the Weight of the Water above it to overcome each Stroke; and so the Labour of Pumping will be greatly encreased. Note, the Piston placed at a greater or less Depth in the Water, makes no Alteration in the Labour of working the Pump.

53. If there were no Hole or Valve in the Piston, but a Valve opening outwards in the Side of the Barrel near the Bottom, then the Machine would become a *Forcing-Pump*; for every Ascent of the Piston would raise the Water into the Barrel, and every Descent would force it thro' the *lateral Valve* into some Pipe or Duct, to any Place or Height you please.

54. There are various Contrivances in the Form and Construction of Pumps; some of which are very curious, as particularly the *Mercurial-Pump*, so call'd by Reason the Exhaustion or *Vacuum* is here effected by Quicksilver, instead of the common Piston. And this Method is easily applicable at large, and without any great Expence. It is capable of producing the Effect of a Pump in the greatest Perfection, as all must allow who see the Model and the Experiment upon it.

55. There is also another very useful Invention of this Kind, *viz.* A *portable Pump*, and which Works by a Piston, indeed, but without any *Friction*; The Piston plays wholly in Water, and does not touch the
Sides

Sides of the Vessel in which it is contain'd. The Stroke in this Pump is very short, and it may be used as an *Exhausting*, a *Lifting*, or a *Forcing-Pump*. The Mechanism is very simple and easy to be understood by the Model; and the Rationale of its working by the Experiment.

57. There is another very ingenious Invention in *Hydraulics*, to shew how a *Water-Mill may be contrived without Wheels* to grind Corn, by a most simple Structure, and with a small Stream of Water. The Model of this Machine is as follows. A B is the Cistern receiving the Stream or Spout of Water which from thence descends by the Tube C D into the Horizontal Trunk E F; this Trunk has two Holes in it on the opposite Side at the Ends, as G at the End F; and another on the opposite Side at the End E. Thro' these Holes the Water rushes out, and by that Means turns round the Machine in a retrograde Manner, or in the Direction F L E M. In the lower Part of the Trunk is fix'd a strong Iron Shaft or Axis I K, which at K turns upon a fine Point in a pivot Hole in the lower Part of the Frame N O P Q; and on the upper Part P Q is fix'd a small circular Piece *a b*, representing the nether Mill-Stone; above there is another *c d* which being fix'd to the Axis I K in the Center I is thereby turn'd very swiftly round upon the

Fig. 15.

the other ; and thus is the End of a Mill by this Means answer'd.

58. The Reason why the Machine must move round very swiftly, will easily appear, if we consider, that if the Trunk had no Hole in it, the Pressure of the Water within would be the same on every Part, and proportional to the Height B D ; but if a Hole be made at G, the Pressure of the Water on that Side and End is diminished ; and the Pressure being greater on the other close Side, will therefore cause that End to begin a Motion from F towards I ; and a Hole being made on the opposite Side at the End E, will double the Cause, and consequently the Velocity of the Machine. 'Tis plain, the Force to turn the Machine is proportional to the Height of the Water B D, and the Distance of the Hole G from the Center of the Machine conjointly.

59. *Newsham's WATER ENGINE*, is rather *Pneumatical* than a *Hydraulic Machine* ; but I shall explain it in this Section. The Design of it is to produce a *continual Stream of Water*, and to project it to *great Distances* ; this is done by Means of *two Forcing Pumps*, which alternately compel Water into a large close Vessel of Air ; the Air is thereby gradually condensed, and compresses the Water beneath with so great Force, that upon turning a Stop-Cock on the upper Part, it rushes out with great Impetuosity

fly thro' a Pipe that comes down into it, and makes a continued Stream, by the Air's being continually condensed and acting continually upon it.

60. To illustrate this, let A B C D be a *Fig. 16*
Glas Globe or Vessel, fill'd about half full with Water B C D; upon the Top is screw'd a Stop-Cork E, with a Pipe H F going to the Bottom of the Water. On the upper Part, at I, is first screw'd on an *injecting Syringe*, by which the Air is thrown in, and greatly condensed in the Part B A D; then turning the Cock, you take off the *Syringe*, and screw on the *Ball and Socket I G*; thro' which, upon opening the Cock, there will issue a continual Stream G K with great Velocity, by the Action of the Air compressing the Water B D.

61. In the same Manner a Variety of *Jet d'Eaus*, and pretty Devices of that Kind, may be practis'd upon this Instrument, by screwing on different Pieces upon the Top of the Cock, particularly if the Vessel be large, a Piece may be screw'd on at I, very full of exceeding small Holes, thro' which the Water may spout obliquely, and form an *artificial Shower of Rain*; in which when the Sun shines strongly, a Rain-Bow will plainly appear, if your Back be turn'd to the Sun, and you view the falling Drops against a *black Wall*

Wall or Cloth. And this Experiment well managed, infallibly confirms the Theory of the Rain-Bow, as deduced from the *Doctrine of Light and Colours* in SECT. II. 22. 30.)



SECTION



Of MOTION and REST; the LAWS of MOTION explained. Of the Composition and Resolution of Forces. The Nature and Use of PENDULUMS explained. A new PYROMETER described to measure the Expansion of Metals. Of the CENTERS of Magnitude, Motion, and Gravity. Of the common Center of Gravity in the System of the Heavenly Bodies. The Principles of MECHANICS explained. Of the several Mechanical Powers; The LEVER, the WHEEL, and AXLE, the PULLEY, the INCLINED PLANE, the WEDGE, and the SCREW; The strongest ARCH to build upon, the Doctrine of WHEEL CARRIAGES, &c.

1. **T**HE Subject of this Section will be to consider the Nature, Laws, and Phænomena of MOTION, and moving Bodies; the Nature and Use of Pendulums; the Centre of Gravity, the Theory of Mechanical Powers and Machines; and the Doctrine of Wheel Carriages; and to demonstrate each Particular by Experiments.

2. MOTION

2. MOTION is the *Change of Place* in Bodies ; and *Rest* is their *Continuance in the same Place*. The most general Cause of Motion with us, is that Power in the Earth and other Bodies we call GRAVITY, by which they attract, gravitate, or move towards one another, unless hinder'd by some intervening Obstacle ; and indeed this is the Cause of all Motion in the larger Bodies of the System.

3. There is besides this an *Animal Cause* or Power of *producing Motion* in Bodies. For any Animal can, at Will, move any Body in any Direction, provided that his *Muscular Force* be not inferior to the *Force of Gravity* in that Body ; and where this happens to be the Case, we have Recourse to Art ; and by Means of many Kinds of Mechanical Contrivances, we are enabled to raise and move such heavy Bodies as far exceed our *natural Strength*. And hence we derive the most useful Science of MECHANICS, or *Construction of mechanical Powers and Machines*.

4. The Manner in which we conceive the Idea of Motion. makes it necessary to distinguish it into two Kinds, *viz. Real and Apparent* ; for we may not only have an Idea of Motion in Bodies when they do *really move*, but also when they *do not move*, but are absolutely at Rest. This Ambiguity in our Ideas of Motion renders us subject to many and very great Mistakes in our
common

common Notions or Judgment of Things. Nor are these Errors of an indifferent Nature; but oftentimes greatly concern the Well-being of Mankind, not only in Regard to the Sciences, but even to *Religion* itself; Witness the Cases of those Degrees which anathematise us for denying the diurnal Motion of the Sun and Stars, and the Case of poor *Galileo* in the Inquisition about 100 Years ago.

5. That we may be able therefore to judge truly of Motion, we must consider, that the Idea is produced in the Mind *by the Passage of the Image of Objects over the Retina in the Bottom of the Eye*. Hence then, if the *Eye be at Rest*, what Ideas we have of Motion must in that Case be of *true or real Motion*, for nothing but Motion in the Object here, can produce a Motion of the Image in the Eye. But, on the other Hand, 'tis as evident, that *if the Eye be in Motion*, an Object before it, tho' at Rest, will have its Image move over the Retina, and so produce a *deceptive Idea of Motion*.

6. Hence with Respect to the Motion of Bodies, there will be three Cases. For (1) *The Eye may be at Rest, and the Object in Motion* (as above) which is the only Case in which we can have an Idea of the *true and real Quantity of Motion*. And even in this plain Case we are liable sometimes to be deceived, *viz.* When the Motion is so very quick

quick as not to admit of any sensible Intervals of Time in passing over sensible Intervals of Space. Thus we see no Motion of the Particles of Light in the *Sun-Beams*; thus also a Body may be turn'd so swiftly as not to appear to move at all; and a *Red Spot* whirl'd swiftly round, makes a *Red Circle* without Motion. All which is evident from common Experience.

7. The second Case is, *when the Object is at Rest, and the Eye in Motion*; and here, as the Motion is altogether apparent, the Idea or Motion we have of it must be the most of all illusive or deceitful. But the Errors of this Sort are often so very gross and obvious, that we can correct them by the least Degree of Reason; thus to a Person in a Ship under Sail, looking out of the Cabbin-Window, the Houses and Trees on the Shore appear to move; but no Man was ever so irrational, as to think such a Motion real. In the same Manner, if our Earth does really turn upon its Axis in 24 Hours *from West to East*, it must necessarily cause an *apparent Motion of the Sun, Moon, and Stars*, in a contrary Direction, *viz. from East to West*, in the same Time.

8. The third Case is, *when the Eye and Object are both in Motion*; and this may be subdivided into three other Cases. As (1) When the Eye and Object both move the *same Way, and with equal Velocity*. In this Case,

Case, 'tis plain, the Image of the Object must always retain the same Place or be at Rest on the Retina, and consequently no Motion of the Object can be perceived. Hence the Ships under Sail seem *at Rest* to a Person shut up in the Cabbin; and we on the Surface of the Earth perceive nothing of its diurnal Motion.

9. Again (2) The Eye and Object may move the same Way with different Velocities. In this Case the Object will appear to *move with the Difference of the two Velocities*, viz. *forwards*, if its Velocity be greater than that of the Eye; or *backwards*, if less. Thus if two Ships A and B sail'd both the same Way, A at the Rate of 3 Miles an Hour, and B at 5; if you were in A, the Ship B would appear to *go forwards* from you at the Rate of 2 Miles *per Hour*; and if you were in B, the Ship A would appear to go backwards or the contrary Way, as fast, while the Ship you are in seems quite at Rest.

10. If (in the 3d Place) they Eye and Object both move, *but in contrary Directions*, or *meet* each other; then the Object would appear to *move with the Sum of the two Velocities*. Thus suppose the two Ships A and B meet each other, each sailing with the Velocities above mentioned; then a Spectator placed in either of them, would see the other approach him with a Velocity of 8 Miles *per Hour*. And hence it appears that

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unless we are well appriz'd of the true State and Circumstances of Bodies which appear to move, or not to move, both in Respect of them and our selves, it is impossible the Judgment we form of their Motion should be correct; but very precarious, and mostly full of Illusion and Error.

11. VELOCITY is the *comparative Swift-ness* or *Slowness* of Bodies in Motion. Thus if the Ship A sail at the Rate of 3 Miles *per* Hour, and B at the Rate of 5 Miles *per* Hour, they are said to move with Velocities which are to each other as 3 to 5.

12. The *Momentum, Force, or Quantity of Motion* in moving Bodies, is all that Power they have to *act upon*, or affect each other in *Collision*, or any Object by striking against it. And this depends upon *two Things*, (1) The *Quantity of Matter* in Bodies; and (2) the *Velocity of their Motion*. For it is easy to understand that when two Bodies move *with equal Velocities*, there can be nothing to make a Difference in the Force of their Strokes, but the *different Quantities of Matter* they contain. Thus a Globe of Gold, and another of Brass, of equal Bulks and Velocities, will strike with Forces which are as their Quantities of Matter, or Weight, *viz.* As $17\frac{1}{2}$ to 8. (See Sect. V. 19.) Thus 100 lb. Weight will strike with 100 Times the Force of 1 lb. moving with the same Velocity.

13. Secondly, on the other Hand, if the *Quantity of Matter continue the same*, 'tis as plain the Force of the Stroke will be exactly proportional to Velocities of Motion. Thus a Bullet projected from the Hand, will not do the Execution as it would if shot from a Gun; because of the much greater Velocity in the latter Case. And therefore the *Quantity of Motion* in any moving Body is to be estimated by its *Quantity of Matter*, and by its *Velocity* conjointly; and therefore it is always as the Product of one multiplied by the other.

14. To illustrate this important Article; *Fig. 1.* it is to be noted, * that if any Body B suspended by a String A B, and raised to any Division of the circular Arch E D, and there let go, it will by its Descent to the lowest Point D, there acquire a Velocity that will be proportional to the Arch of Descent, and therefore may be measured by it. That is, if a Body descend from the Points B, C, E, the Velocities acquired by those Descents will be in the Point D, as the Arches B D, C D, and E D respectively.

15. Therefore let the Body B of 3 Ounces, *Fig. 2.* descend from the 5th Division, and strike the Obstacle D, and afterwards let it descend from the 9th Division, to strike the same Obstacle, then will the Magnitude of the Strokes be as the Velocities, viz. The Force of the first Stroke to that of the second, as 5 to 9.

16. But

Fig. 3.

16. But if the Ball B of 3 Ounces, descend from the 5th Division, and another Ball G of 2 Ounces descend from the 9th Division, the Stroke of B will be to that of G, as 3 Times 5 or 15, to 2 Times 9 or 18. And thus, I presume, the Nature of Force or Momentum, or Quantity of Motion is very easy to be understood from what has been premised.

17. Sir *Isaac Newton* has consider'd all the Affections of Motion under *three general Heads*, which he calls the *three Laws of Motion*, and sometimes they are call'd the *Laws of Nature*, because they are observed by all Bodies whatsoever. The first of these is, *That every Body endeavours to continue in a State of Rest, or moving uniformly in a right Line, unless so far as it is compell'd to change that State by Forces impress'd.*

18. This is evident by considering, that each Particle of Matter is absolutely inert and passive; and so quite indifferent to Rest or Motion; and if it chance to be *at Rest*, since it has no Principle of Action in it self, it cannot of itself change that State; and for the same Reason, if it be once in Motion, it must necessarily so continue, all Obstacles being supposed away. The Motion likewise must be in a right Line, there being nothing in Matter itself to alter that Direction of Motion which it had in the Beginning.

19. Thus

19. Thus then it appears, that all the Change that is at any Time made in Bodies, is by the Action of external Forces impress'd. Bodies at Rest, without being acted upon by external Objects, we can easily conceive, will always remain at Rest. And 'tis as true, that Bodies in Motion, where there is no resisting Medium or Obstacle, will preserve their Motions undiminish'd; witness the *Planets* and *Comets*. But the Ball on the Billiard-Table, or the Bowl on the Green, 'tis evident, loose their Motion only by the Resistance of the Plane or Parts on which they move. If the Axis of a Wheel in Motion were to move on other moveable Wheels the Motion would continue much longer; because Parts in Motion afford not the Resistance to Bodies as when they are fixed; again, if the Axles of these moveable Wheels were to move on the Peripheries of other moveable Wheels, the Resistance or Friction would be still farther diminished, and the Motion of the first Wheel would be continued much longer. And if the Friction could be diminished *ad infinitum*, the Motion would become *perpetual*; all which we illustrate by Experiments on a *Machine of Friction-Wheels*.

20. Hence it evidently follows, that a *perpetual Motion* is absolutely impossible to be effected by any human Art or Contrivance; because no Machine can be constructed with

a Motion of the Parts one upon another, and consequently not without Friction, which will by Degrees destroy all the Motion communicated to the same by any Agent whatsoever. We also hence see the Reason why the *Planets and Comets* continue to move with their original Velocities undiminished; as they are Bodies vastly large, moving very swiftly, in free or unresisting Mediums.

21. The *second Law of Motion*, is, the *Change of Motion is always proportional to the generating Force impress'd; and is always made according to the right Line in which that Force is impress'd*; that is, a double Force will produce a double Quantity of Motion; a triple Force, triple that Quantity, and so on. Thus if the Body A by an Impetus from another Body B, were moving in the Direction AD; and at the Instant it was in A another Force were impress'd upon it by the Body C in the Direction AF; then a Change would be made in the first Motion of the Body A, both in Regard of its Velocity and Direction.

Fig. 4.

22. For supposing by the Stroke of B the Body A would describe the Space or Line AD in one Second of Time; and that by the Stroke of C, it would describe the Line AF in the same Time, then 'tis plain by both Forces together, it must proceed with a Velocity greater than either singly, and in a Direction which is compounded of both the others: For draw FE parallel to AD, and

and D E parallel to A F, intersecting each other in E, and join A E, and that Line A E shall be the Direction which the Body A will pursue by this compound Motion; and the Space A E will be described by it in the same Time as A D or A F by the single Impulses of B, or C.

23. For the Force impress'd by C does not at all alter its Velocity of approaching to the Line D E, and therefore at the End of the given Time it will be form'd in that Line; for the same Reason, by the Force of C, it will arrive to, and be form'd in the Line F E; and therefore at the End of the given Time, it will be found in the Point E, common to both, after it has described the Line or Space A E.

24. Hence the most useful Doctrine of *the Composition and Resolution of Forces* is derived. For any two Forces may be represented or estimated by two Sides of a Parallelogram A D E F analogous to them; and then the Diagonal will express the Force compounded of both. Also, on the other Hand, any given Force A E may be resolved into two others A D, A F, acting in different Direction, according to which there may arise a great Variety of Cases, *which I have elsewhere explained.*

25. The *third Law of Motion* is, that *Action and Re-action between Bodies are equal and in contrary Directions.* For since the

Impact or stroke between the two Bodies is but one simple individual Thing, it can effect both of them, but in one and the same Manner and Degree, or they must act upon or effect each other mutually and equally thereby. If a Horse draws a Stone by Means of a Rope, all the Force by which they act upon each other, is expressed in the *Tension of the Rope*, but that is the same throughout, and therefore equal at each End, upon the Horse and upon the Stone.

26. The Question is, then if the *Horse and Stone act equally on each other, how it comes to pass that the Horse can move the Stone?* The Answer is easy, viz. Because tho' there be an *Equality of Action*, there may not be an *Equality of Force* between the Horse and Stone; for when that is the Case there can be no Motion in either. Thus suppose the Muscular Force of the Horse were just equal to 500lb Weight; if a Stone of that Weight was fasten'd to a Rope and hung over a Pulley to gravitate freely; the Horse could not put it into Motion, but there would be an *Equilibrium* of Forces between them. But if the Stone weigh'd only 400lb, then it could only by (*Reaction*) destroy 400 out of the 500lb in the Horse, and the Difference of 100lb in the superior Force of the Horse would put the Stone into Motion. As, on the other Hand, if the Stone weigh'd 600lb, it would draw

draw the Horse backwards with the superior Force or Difference of 100lb Weight.

27. Thus when inanimate Bodies act upon each other by Attraction, or any other Force, they are equally affected thereby; the Loadstone and Iron are equally acted upon by the magnetic Power. Two magnetic Needles equally attract, and produce equal Quantities of Motion in each other; the same is to be understood of the Earth, and a Stone falling upon it; in all these Cases, what is wanting in Velocity is compensated in Quantity of Matter, so that one multiplied into the other always make on each Side an equal Force (See *Art. 12, 13.*)

28. On this Principle it is, that *Fishes swim*, and *Birds fly*, and *Men row a Boat*, because when the Medium is acted upon by the *Fin, Wing or Oar*, in any one Direction, by an *equal Reaction*, it moves the Fish, the Bird, and the Boat in a Direction just the contrary. Tho I can't help thinking, that besides this *mechanical Action or Power*, there is something of an innate Energy in all those Animals by which they move very swiftly, with scarce any sensible Motion of the Fins or Wings. And this *Je ne sçai quoi* it is in Spiders, by which they fly in any Direction they please, without any external *visible Means* at all.

29. I have already observed, that a Body falls towards the Earth by the Power of Gra-

vity; and since that Power acts constantly upon it, its Velocity must be *constantly accelerated*; and since near the Earth's Surface, the Action of Gravity may be supposed uniform, there will in *equal Times*, be equal Increments of *Velocity*, and therefore *the Velocity of falling Bodies will be always proportional to the Time of the Fall*. Hence it is, than since the Space descended thro' increases both with the Velocity and Time of the Fall, it must be *proportional to the Square of either*. Therefore it being well known by Experiment, that a Body will descend thro' 16,2 Feet nearly in one Second, it will in two Seconds fall thro' 4 Times 16, 2 Feet, or 64,8 Feet; and in 3 Seconds, thro' 9 Times 16,2 or 146 Feet nearly; and so on, for any other Number of Seconds.

Fig. 5.

30. Let B C E be an *inclined Plane*, then if any Body be laid on the highest Part B it will descend to the lowest Point C by the Power of Gravity; and for the same Reason, if the Body were suspended by a String from any Point A, and the Plane taken away, it would then also descend in the Arch of a Circle B C to the lowest Point C; but it will not there rest, but the Velocity which it has there acquired in the Descent, will carry it from C to D on the other Side, so that the Arch C D is nearly equal to B C; from thence it will again return to B, then back again to D, and so on till all the Motion

tion be gradually destroyed by the Resistance of the Medium, and the Friction at the Point of Suspension A, a Body vibrating forwards and Backwards in this Manner, is call'd a PENDULUM.

31. If the Pendulum A B be very long, and the Arch B D thro' which it vibrates, very small, the *Times of the Vibrations will be nearly equal*; and hence it came to be applied to *Clock-Work*, for the Regulation of the Movements, which are design'd to divide the larger Portions of Time into smaller equal Parts. And for this Purpose it would be the best Instrument ever yet invented, were it not for one Thing, *viz.* the *Lengthening and Shortening* of the Metalline Rod, with which they are made, by *Heat and Cold*; for as the Pendulum, by Heat, becomes longer, it vibrates slower, and the Clock *looses Time*; as on the contrary being shorten'd by Cold, it vibrates quicker, and the Clock goes *too fast*; so that a Clock can never make a true or equal Division of Time unless the Pendulum continues of the same Length, and vibrates in equal Times.

32. To shew that Metals expand by Heat and contract by Cold, an Instrument call'd the PYROMETER has been invented, and *Fig. 6.* contrived in various Forms. Among others, I shall give one of my own, which I judge to be the most simple Structure of any extant. It is represented in *Fig. 6.* where A B is the

L 4

Basis

Basis; at one End of which is a brass Frame C D, in which are contain'd two Wheels, one large one E, and another small one F, on their Axles. At the other End is fix'd a large and strong upright Piece of Iron I K. The Bar of Metal for the Experiment is G H; one End of which is fix'd on the Iron Bar by Means of a Hole at K, and the other End H is laid on the Axle of the Wheel E; the Bar of Metal is heated by the Candles placed underneath on the Pedestal L. By this Means it will encrease in Length, and turn the Axle and its Wheel E, which is connected by a String to the small Wheel F; and which being moved, carries the Index P over a large graduated Circle M N O, by which the Quantity of Expansion may in different Metals be estimated as follows.

33. Suppose the Bar G H extend in Length only *One Ten Thousandth Part of an Inch*, this will move the Axle of the Wheel E just so much about; and suppose the Diameter of the Wheel ten times that of the Axle, the Surface of the Wheel E will be moved just *One Thousandth Part of an Inch*. As this Wheel is connected with the small Wheel F, that Wheel F must be moved just so much likewise: And now, in the last Place, let us suppose the Diameter of the Wheel F to be $\frac{1}{20}$ Part of the large graduated Circle M N O; then since the Index P moves on the Axle of the small Wheel, it will

will move over 20 Times the Space as the Surface of that Wheel does in the same Time, that is, it will move over $\frac{20}{1000}$ of an Inch, or *one fiftiest Part of an Inch*; which is visible to the Eye. And so this Machine tho' small, will shew the Extention of Metals to the *ten thousandth Part of an Inch*.

34. If the Bar GH be made red Hot, and laid on, it will be seen how much it will be contracted or shorten'd when cold. If Bars of different Metals and of the same Size were heated with the same Candles, in the same Time, it would easily appear what Difference there is in the expansive Power of the several Metals. This Instrument might also be used as a *Thermometer*, to measure the various Degrees of Heat; it might begin where *Farenheight's* ends, and be easily reduced to his Scale.

35. But, lastly perhaps no Instrument can be contrived so much for the Purpose of an *HYGROMETER* as this; for if the Bar GH be a long Slip of Wood, (*Deal* or *Elm*, for Instance) cut across the Grain, and glued together End-ways, and be laid on this Machine as before, with a Piece of Metal on the under Side, and a small Weight above where it lies on the Axle; then the *Moisture of the Air* will make it expand, and Dryness will contract its Length, both which will be sufficiently shewn by the Index P on the large Circle MNO.

Fig. 7.

36. There have been different Methods contrived to remedy this natural Defect of Pendulums, two of which I shall here mention. The first is of the Invention of Mr. *Graham*, and depends on this Consideration, that any Rod A B suspended and put into Motion is as much a Pendulum as a common One consisting of a Wire and Bob C D. And if the Rod or Bar A B be of a *uniform Figure* throughout, it will vibrate in the same Time with a Bob-Pendulum C D, which is just two Thirds of its Length. The Center E, therefore, in the Rod, which is opposite to the Center of the Ball D, is call'd the *Center of Oscillation*. If therefore A B be a Brass Tube fill'd with Quicksilver, the Tube itself, by Heat, will lengthen downwards, but the Column of Mercury in it will be expanded upwards; and so, since A E is double E B, the Mercury will rise upwards more than the Tube lengthens downward, 'tis plain the Center of Oscillation E may by this Means be kept nearly at the same Distance from the Point of Suspension; and so the Time of Vibration will be more equable, or nearly the same in different Degrees of Heat and Cold.

37. The Point E is also the *Center of Percussion*, or it is that Point in which the Forces of all the Particles of the Rod are united in striking; so that Stroke made from the
the

the Point E is greater than any other that can be made from any other Point in the Rod.

38. The other is a *French Invention*, and consists of a Kind of compound Pendulum as follows. A B is a Rod of Iron, in which Fig. 8. on the upper Part is a fix'd Piece A C; in this is fasten'd a Piece of Copper C D which on its lower End bears on the End of a Lever D E, moveable on the Center B in the End of the Iron Rod; from the End of the Lever E, there hangs the Ball of the Pendulum F. Now since Copper will extend with Heat, considerably more than Iron, the Point D of the Rod C D will push down the End of the Lever D, and by that Means raise the Weight F upwards; and consequently if every Part could be truly adjusted, the Center of Oscillation of this Pendulum might always be in the same Place, and so the Clock keep Time. But the most curious and artful Contrivance of this Nature is to be seen in that Sort of Clock-work, of which Mr. *Harrison* is the Inventor, which cannot be here describ'd.

39. It is well known by Experiment, that a Pendulum which vibrates Seconds is $39\frac{1}{8}$ Inches long; also that *the Lengths of Pendulums are as the Squares of the Times of Vibration*; therefore a Pendulum that vibrates in half a Second must be $\frac{1}{4}$ Part of $39\frac{1}{8}$ or $9\frac{8}{16}$ Inches long. And by such a Pendulum we can easily *measure the Distance of a cloud*
when

when it Thunders and Lightens. For holding such a Pendulum in the Hand, as soon as you see the *Lightening*, let it go, and tell the Vibrations it makes till you hear the *Thunder*, you have then the Number of Half-seconds, for every one of which you must allow 571 Feet, and then will the Distance of the Cloud be known in Feet precisely. For by many Experiments it has been found, that Sound goes thro' 1142 Feet uniformly in every Second of Time. In the same Manner the Distance of a Ship on the Sea may be measured by the *Fire and Report* of a Gun.

40. The Pendulum has been of Use also in helping to discover the *true Figure of the Earth*; for a Pendulum that vibrates Seconds here, will vibrate more than 60 Times in an Hour, under the polar Circle, and less than 60 under the Equator; and as this Difference is greater than what could arise from Heat and Cold, it was rightly concluded to be owing to a different Power of Gravity on the Pendulum in those places, occasion'd by the different Distances from the Center of the Earth. This gave Occasion for an actual Mensuration of a Degree under the Equator and Polar Circle, by which it appear'd *that the Diameter of the Equator exceeded the Axis of the Earth by 80 or 90 Miles*; and that therefore *the Earth is not a Sphere, but an oblate Spheroid.*

41. In

41. In a mechanical Consideration of Bodies, there are three Sorts of Centers that offer themselves to our View, viz. the *Center of Magnitude*, *Motion*, and *Gravity*. The *Center of Magnitude* is that Point in any Body which is equally distant from all the external Parts of that Body. The *Center of Motion* is that Point in the Surface, or that Line in a solid Body that remains at Rest, while all the other Parts of the Body move about it. And the *Center of Gravity* is that Point which being supported, the whole Body is supported, or kept from falling. The Manner of finding this Point in any Body, is best shewn by Experiment.

42. If two or more Bodies are connected together, or any how depend on each other, as by Attraction, &c. there is always a *common Center of Gravity* between them. Thus for Instance, let E and M be the Earth and Moon, and C their *common Center of Gravity*; the Distance thereof E C from the Earth, is to the Distance C M from the Moon as the Quantity of Matter in the Moon is to that in the Earth, which is nearly as 1 to 40, and therefore allowing the Distance of the Moon from the Earth to be 240,000 Miles, the Distance E C will be a little more than 1800 Miles. And it is this Center C, that both the Earth and the Moon continually revolve about. And also it is the same Center C (and not the Center of the Earth) that

Fig. 9;

that describes the annual Orbit about the Sun. There is also alike common Center of Gravity between the *Sun and all the Planets*, and about which the Sun, as well as all the Planets revolves. So that truly speaking, there is no Body in the whole System at Rest, or the Center of Motion to others.

43. Any Machine or Instrument is call'd a *mechanical Power*, by which we are enabled to raise or move such heavy Bodies as exceed our natural Force or Strength; and this may be done two Ways, viz. by *increasing the Power which acts against the heavy Body*; or, Secondly, by *diminishing the Weight of the Body*, the Power is increased by increasing the *Velocity of Motion* (*Art. 13.*) And there are three Sorts of Machines which do this, viz. the *Lever*, the *Pulley*, and the *Wheel*, and *Axle*. And the Weight of Bodies is diminish'd, or their Action against the Power lessen'd, by laying them on an *inclined Plane*, to which we refer the *Wedge* and the *Screw*.

Fig. 10.

44. The LEVER is an inflexible Line or Rod A B moveable about a Point C, on which it is supported, and is call'd the *Fulcrum*; at different Distances from this Point at each End, are applied the Weight W, and the Power P, which are in Equilibrio with each other. Now whenever the Lever is put into Motion, 'tis evident, the Velocity of the Power will be to that of the Weight

Weight as the Distance CB to the Distances AC ; and therefore the Quantity of Matter in P will be less than that in W in the same Proportion. And therefore *so much are the natural Powers of Bodies encreased by this Machine.*

45. The PULLEY, being only a Wheel, is singly no *mechanical Power*, because Bodies suspended upon it have *equal Velocities of Motion*; but a Combination of two or more Pullies constitute a *mechanical Machine*. For 'tis evident the Velocity of the Power P is greater than that of the Weight W , in proportion *as the Number of Ropes belonging to Fig. 4. the lower Set or Box of Pullies exceeds Unity*. Thus in the Figure the Weight W hangs by five Ropes, and the Power P by one, therefore, when the Weight is raised one Inch, the power will descend through five; and its Force is therefore encreas'd five Times.

46. I shall just here remark, that a *just Ballance* is in the Nature of a *single Pulley*; and a *false Ballance of the Lever*. And yet the *Steel-yard*, which is a Lever also, is a *just Ballance* when truly made, and one of the best Instruments of this Kind. The Nature of the Ballance, especially the *false one* will be fully illustrated by Experiments.

47. The WHEEL AND AXLE, is a very *Fig. 12.* useful *Mechanical Power*; because the Power P hanging from the Circumference
CD

CD of the Wheel, will have a Velocity greater than that of the Weight W on the Axle in Proportion as the Diameter of the Wheel is greater than that of the Axle, that is, of 12 to 1, in the Figure. Of this Kind are all Winches, Windlasses, Capstans, Crane-Wheels, &c.

Fig. 13.

48. The INCLINED PLANE, is a *mechanical Power*, by diminishing the Weight of Bodies laid thereon. For, let the Plane be AB, and DEF a Body lying upon it, this Body will gravitate in the Direction of the Line NH, perpendicular to the Horizon BC, and cutting the Plane in G. Suppose therefore, the Line NG represent the whole Gravity of the Body, draw NF perpendicular to the Plane; then will the whole Gravity NG be resolved into two Parts NF and FG (by *Art. 24.*) but since the Part NF is perpendicular to the Plane, it will be all destroyed by the *equal Reaction* thereof (*Art. 25.*) and since the other Part FG is parallel to the Plane, it will tend to move the Body down upon it.

49. Now this *residual Gravity*, (which is all we have to overcome in moving Bodies up the Plane) is to the *whole Gravity*, of the Body, as GF to GN, or as GH to GB, that is, as AC to AB, viz. *as the Height of the Plane to its Length*; and therefore, the more the Plane is inclined to the Horizon, the less will be the Weight of Bodies lying on

on them, which we act against; and consequently the greater will be the Advantage of this Machine.

50. The WEDGE, ABC , must certainly be a *mechanical Power*, as it consists of *two inclined Planes*, join'd by their Basis. But tho' the Plane is doubled in the Wedge yet the Force of the Wedge is not *double*, but only *equal to that of a single Plane*, AC , Fig. 14 or BC ; for each Plane acts against equal Forces by the fixed Base, DC , common to them both. And therefore, the Force of the Wedge is still express'd by the Proportion of AC to AD , viz. the Length of the Side to half the Thickness. Of this Kind is the Knife, the Axe, the Chisel, &c.

51. The SCREW AB , is generally reckoned a *simple mechanical Power*, but very mistakenly, since we never work it without the Lever FG , or something analogous to it. This Machine when rightly consider'd, is nothing but an *inclined Plane*, coiled round a Fig. 15 Cylinder; and as an heavy Body, is raised only through the perpendicular Distance of two Threads while it has pass'd once round the Cylinder, therefore, the Power is to the Weight (in this Machine alone) as the Distance of the Threads, to the Circumference of the Cylinder; that is, as the Height to the Length of the Plane, as before.

52. But, as I said, since to this Machine we generally add the Lever, they become
M
together

together a Machine of very great Force, and not only serves in many Cases for moving or raising Weights, but its Make adapts it to answer all the useful Purposes of *Compression*; and for *holding and binding Bodies together*. And perhaps, there is not a Machine so universally necessary in every Business of Life as the *Screw*.

53. The Computations of Force in the foregoing Machines, is upon Supposition, that there is *no Friction between the moving Parts*; but as no Machine can be contrived without it, and when several are combin'd together into one compound Machine, it is found, that a very considerable Allowance must be made for it; *viz*, near a *third Part of a whole acquired Force*, must be allowed to overcome the Friction of the several Parts. This being done, the Force of any compound Machine is known, by *multiplying together the several Forces of all the simple Powers of which it consists*.

Fig. 16. 54. If a Chain be suspended at each End, upon the Points A C, it will by its Weight, settle itself into a Curve A B C, call'd the *Catenaria*; and, since all the Parts of this Curve are in Equilibrio by their mutual Gravity, it is evident, that it is preferable to any other for the *Form of an Arch to build upon*. For, if this Curve be inverted, or turned with its convex Part upwards, it will support itself. And it is demonstrated, that

that when the Height of the Arch DB, and its Thickness at Top BE, are given, then *Fig. 17.* these will be an Equilibrium in all Parts, *When the Half-length of the Chain AB, is a Mean proportional between the Height DB, and the Sum of the Height, and twice the Thickness BE.* That is, when $DB: AB:: AB: DB \times 2 BE$.

55. In the last Place, with Respect to WHEEL CARRIAGES, we may easily understand, that a large Wheel GHI, will go *Fig. 18.* over any Obstacle with more Ease than a lesser one BCD. For, suppose BE, an Obstacle placed before the low Wheel, and equal in Height to the Radius, or Semidiameter OD, then, if the Wheel be drawn in the Direction AB, parallel to the Horizon EI, 'tis plain the Point of the Wheel at B, will be drawn directly against the Top of the Obstacle, and also its Center O; and so the whole Motion of the Wheel will be destroyed by the equal Re-action of the Obstacle BE, supposed to be fix'd. But the same Obstacle being placed before the larger Wheel at EG, the Point G in the Wheel, is below the Center Q, and consequently, when the Wheel is drawn horizontally, the Point G presses the Obstacle obliquely, and so only a Part of the Force is destroyed by Re-action; the other remaining Part will tend to raise the Wheel over the Obstacle. Since then, a high Wheel will go over an Obstacle,

Obstacle, when a low Wheel will not; it follows, *they are most advantageous for Carriage.* And this we sufficiently shew by Experiments, *in loading Waggons before and behind, &c.*

Fig. 19.

56. Another Contrivance for facilitating the Draft of loaded Carriages, is, by placing a Box E F, containing two *moveable Wheels*, A B, C D, over the Ends of both Axle-Trees, in such Manner, that the End G, of the Axle may lie in the Interfection of the two Wheels; and therefore, when the Waggon is loaded, it will bear wholly by these Friction Wheels, on the Axles; and when drawn along, the Friction Wheels will move with the Axles, by which Means the Friction, or Resistance in the common Way, is abated nearly in the Proportion of the Diameter of the Friction Wheel to that of the Axle. All which will appear very plainly, by Experiments made on a Carriage of this Sort.

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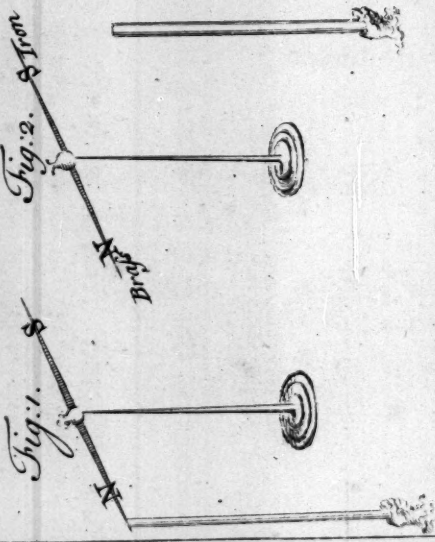


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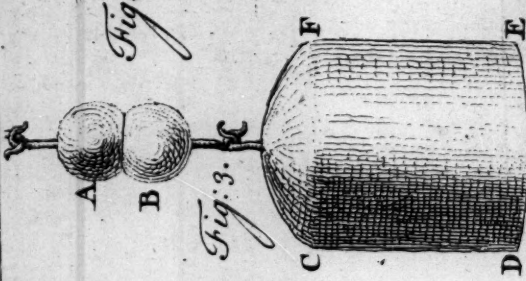


Fig. 4.



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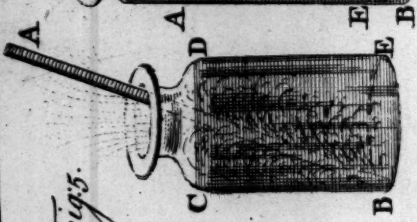


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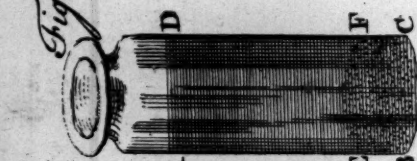


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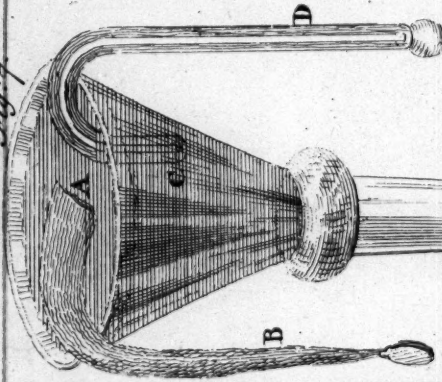


Fig. 9.



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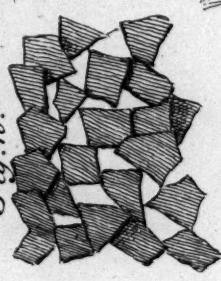


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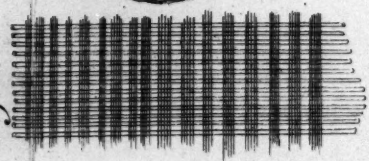


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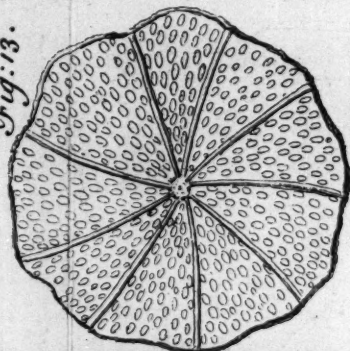


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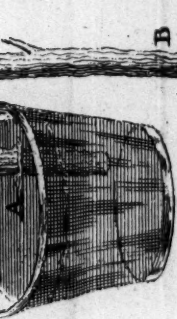


Fig. 17.



Fig. 18.



Fig. 19.



Fig. 20.

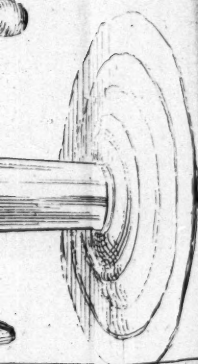


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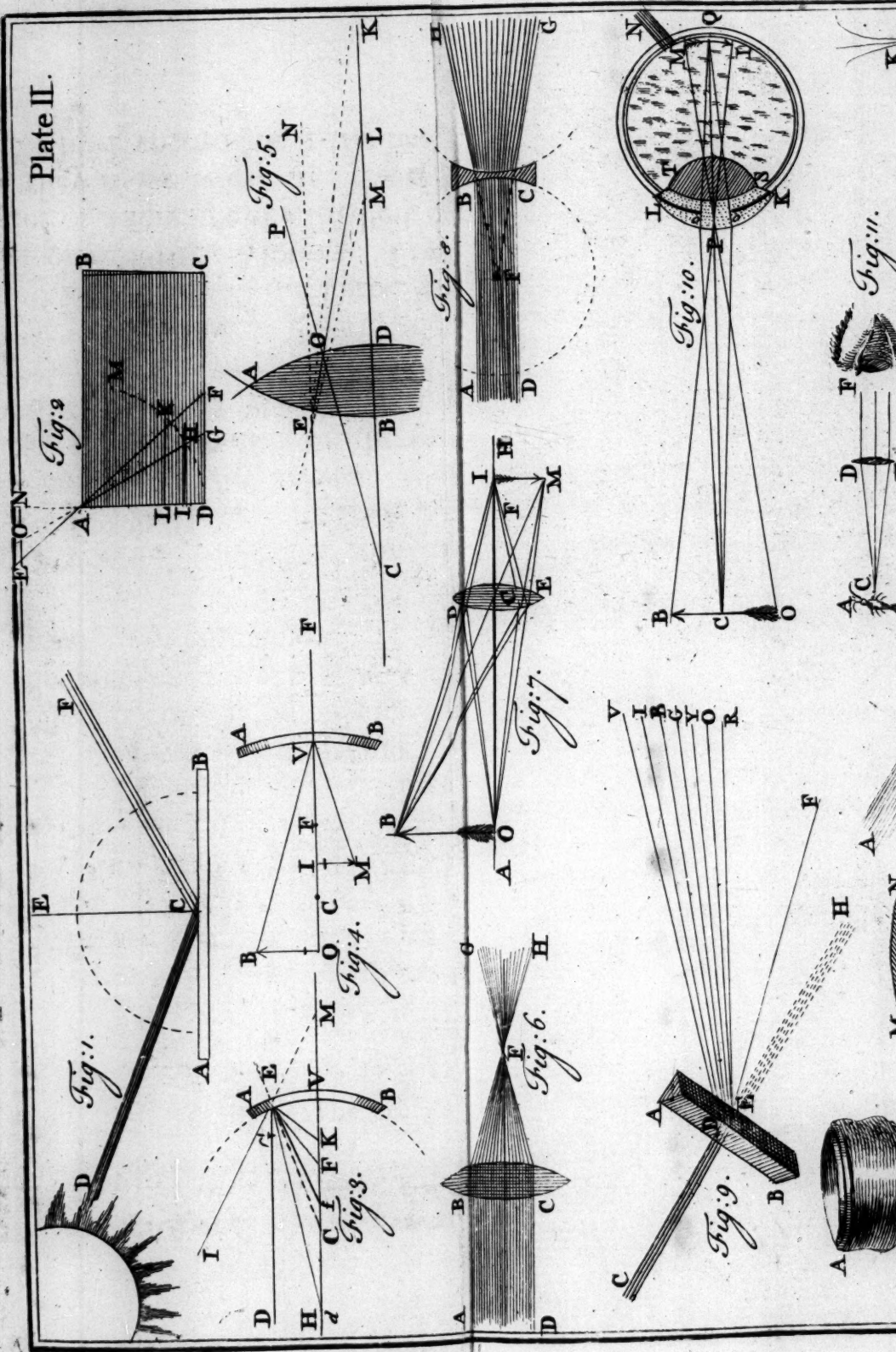
Fig. 16.



Fig. 15.

E. Bowen sculp.

Plate II.



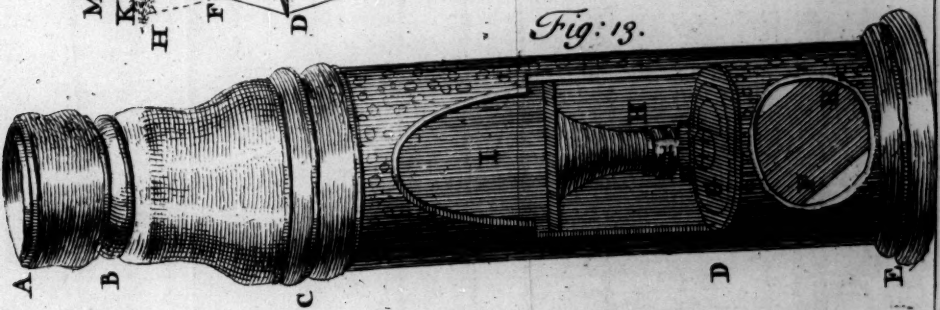


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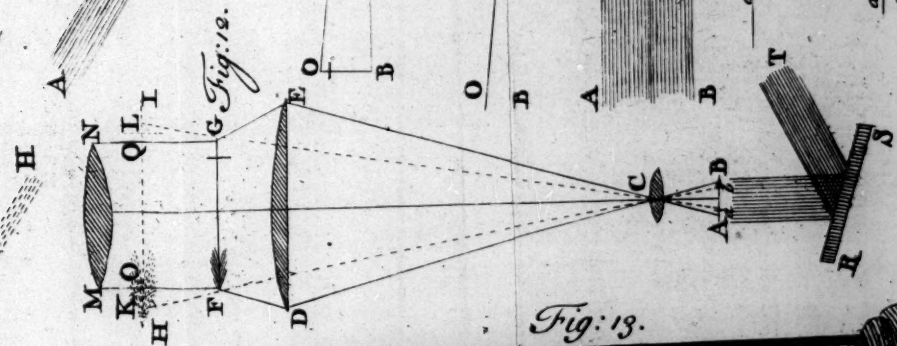


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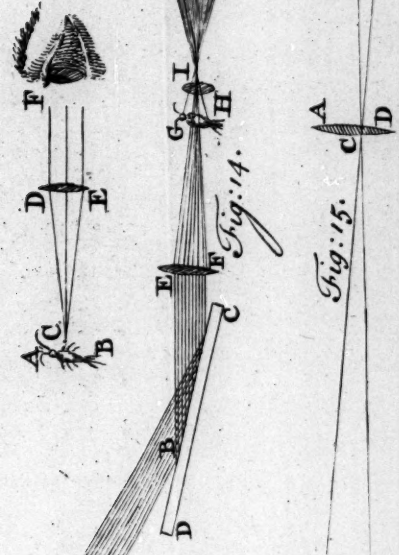


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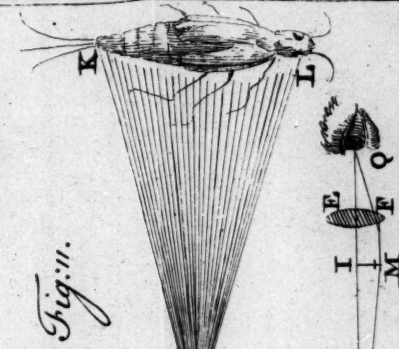


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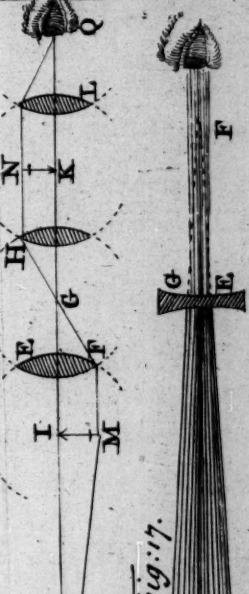


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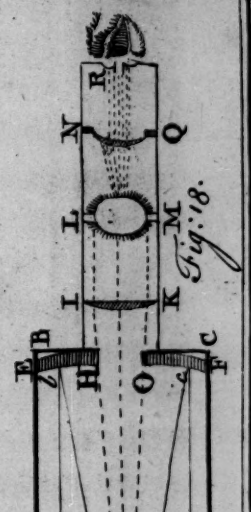


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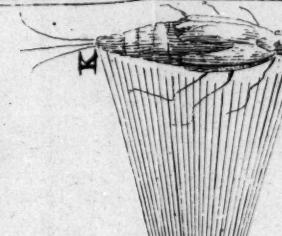
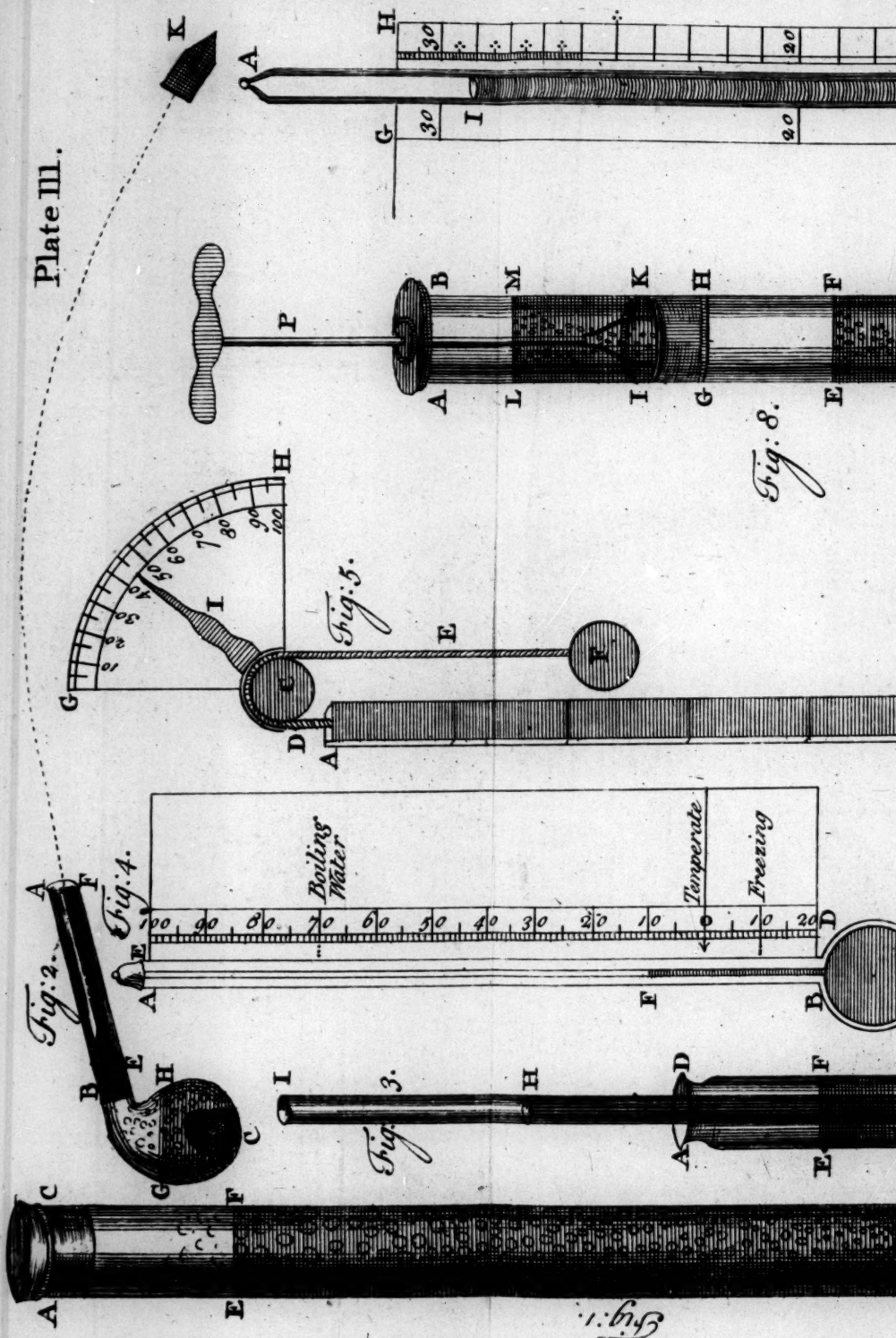


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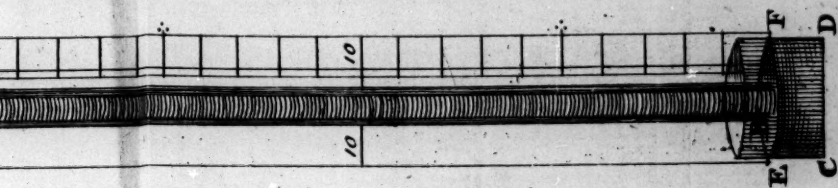


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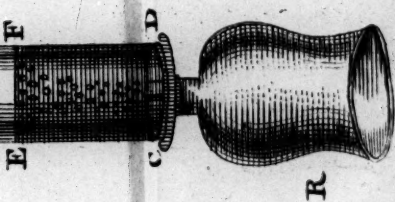
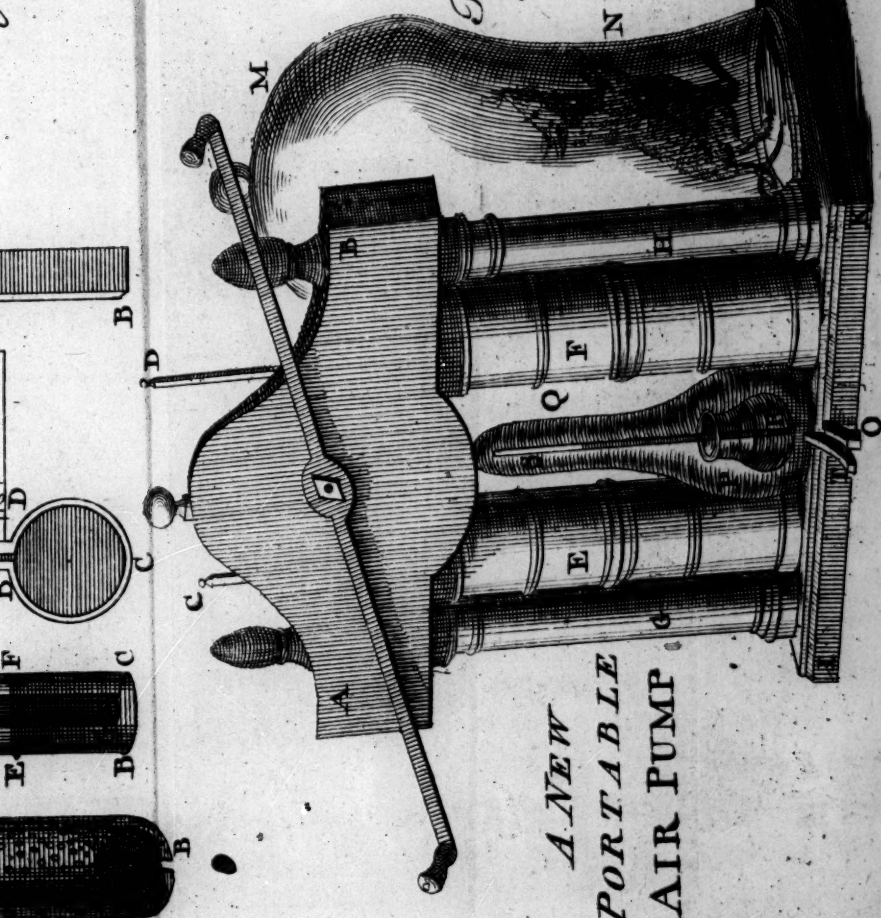
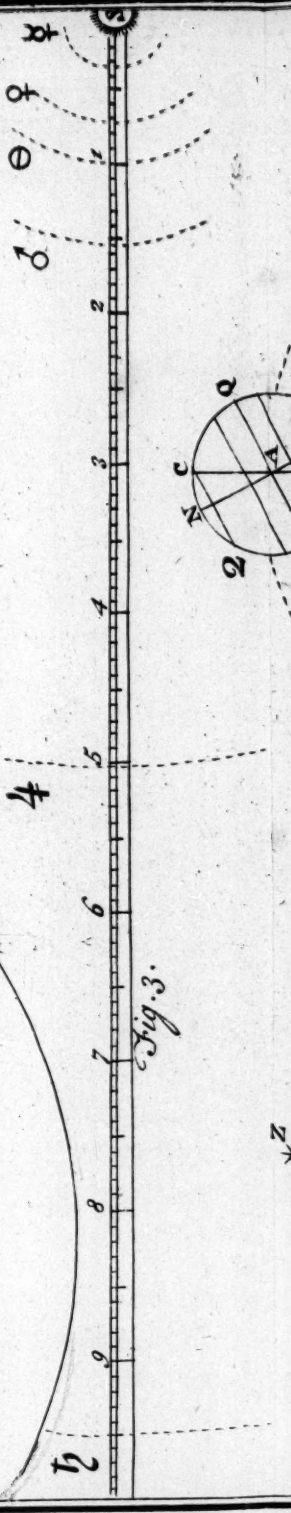
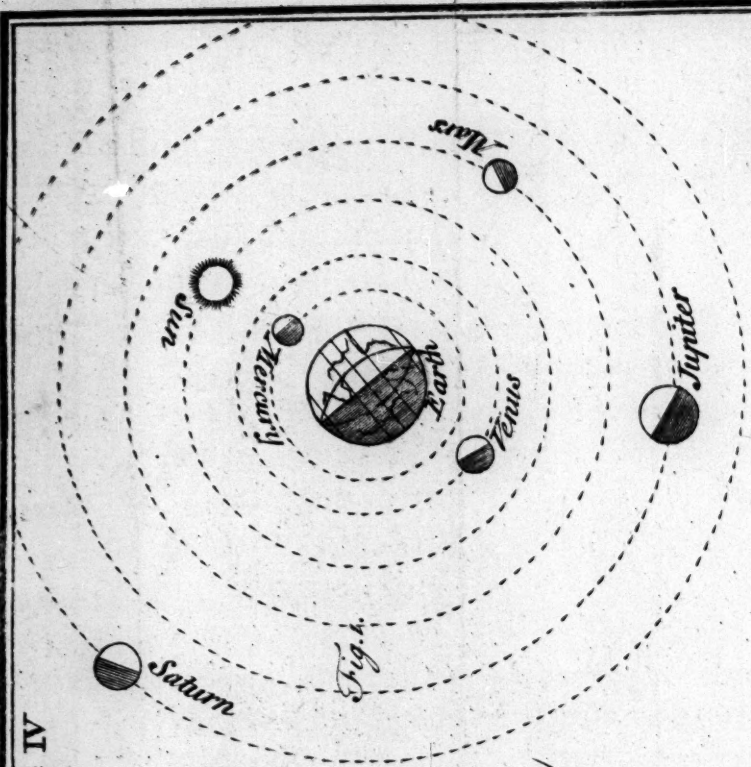
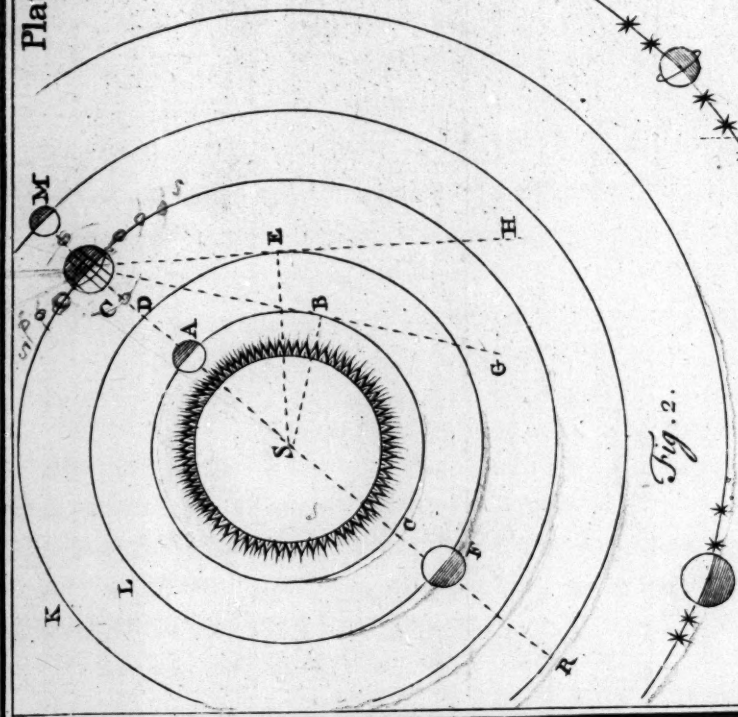


Fig. 7.



*A NEW
PORTABLE
AIR PUMP*

Plate IV



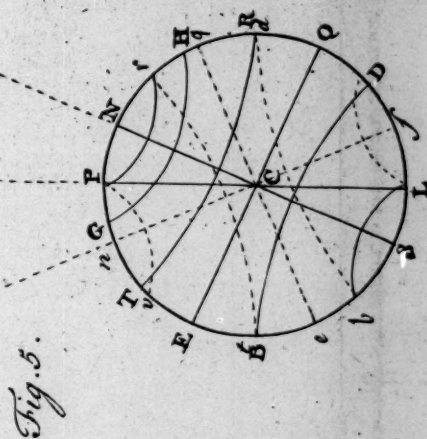
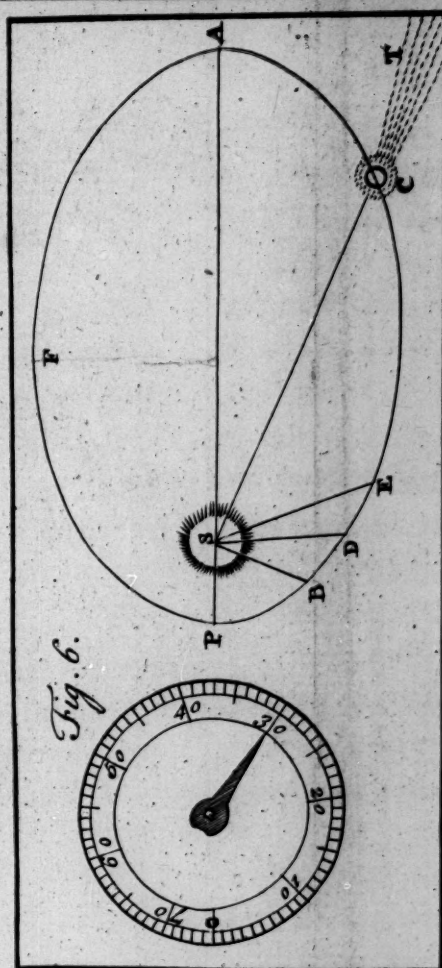
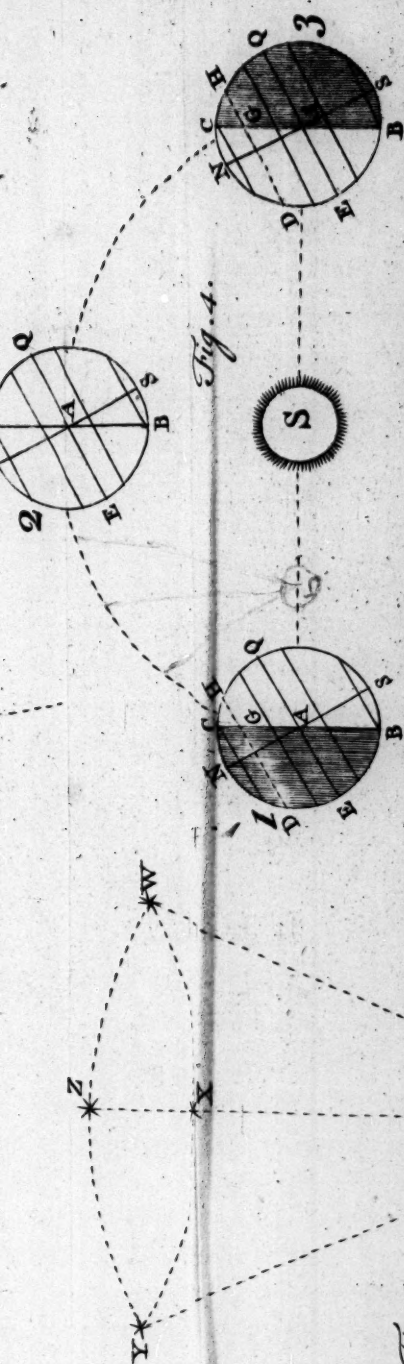
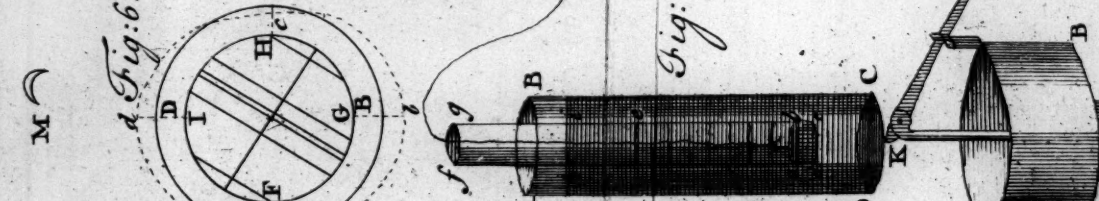
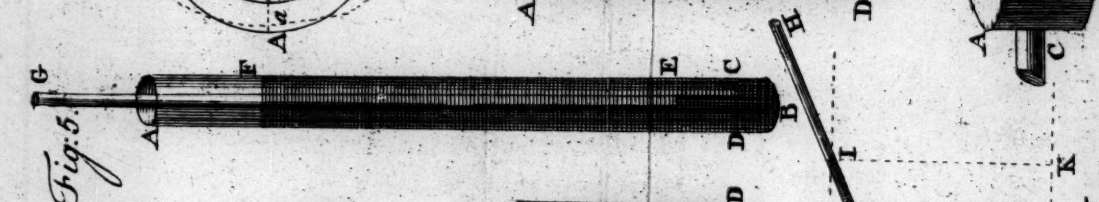
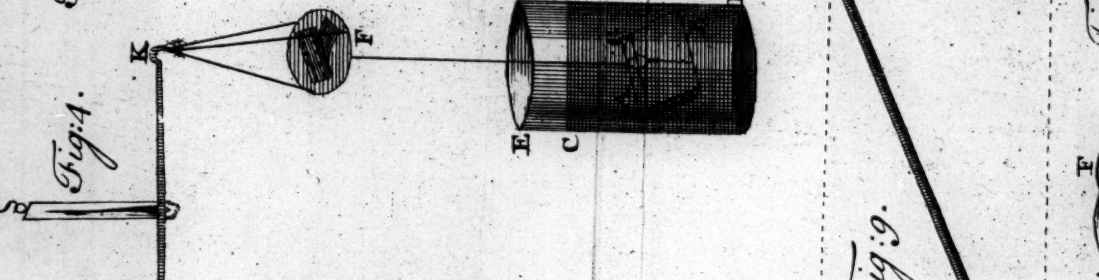
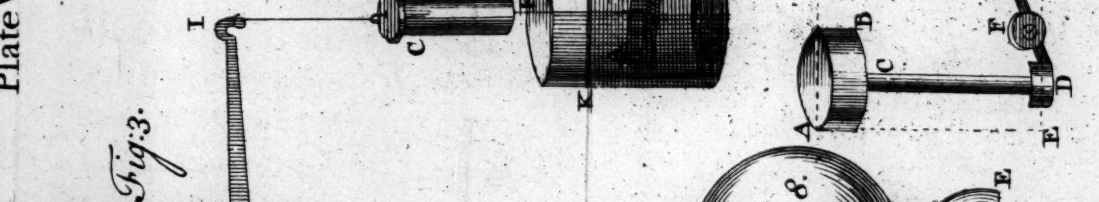
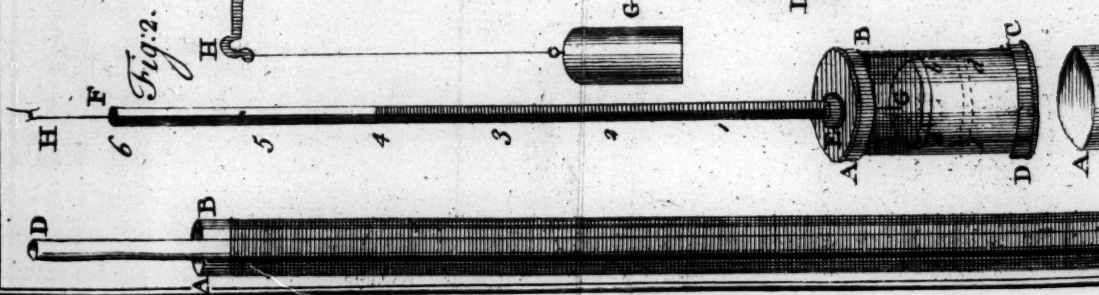


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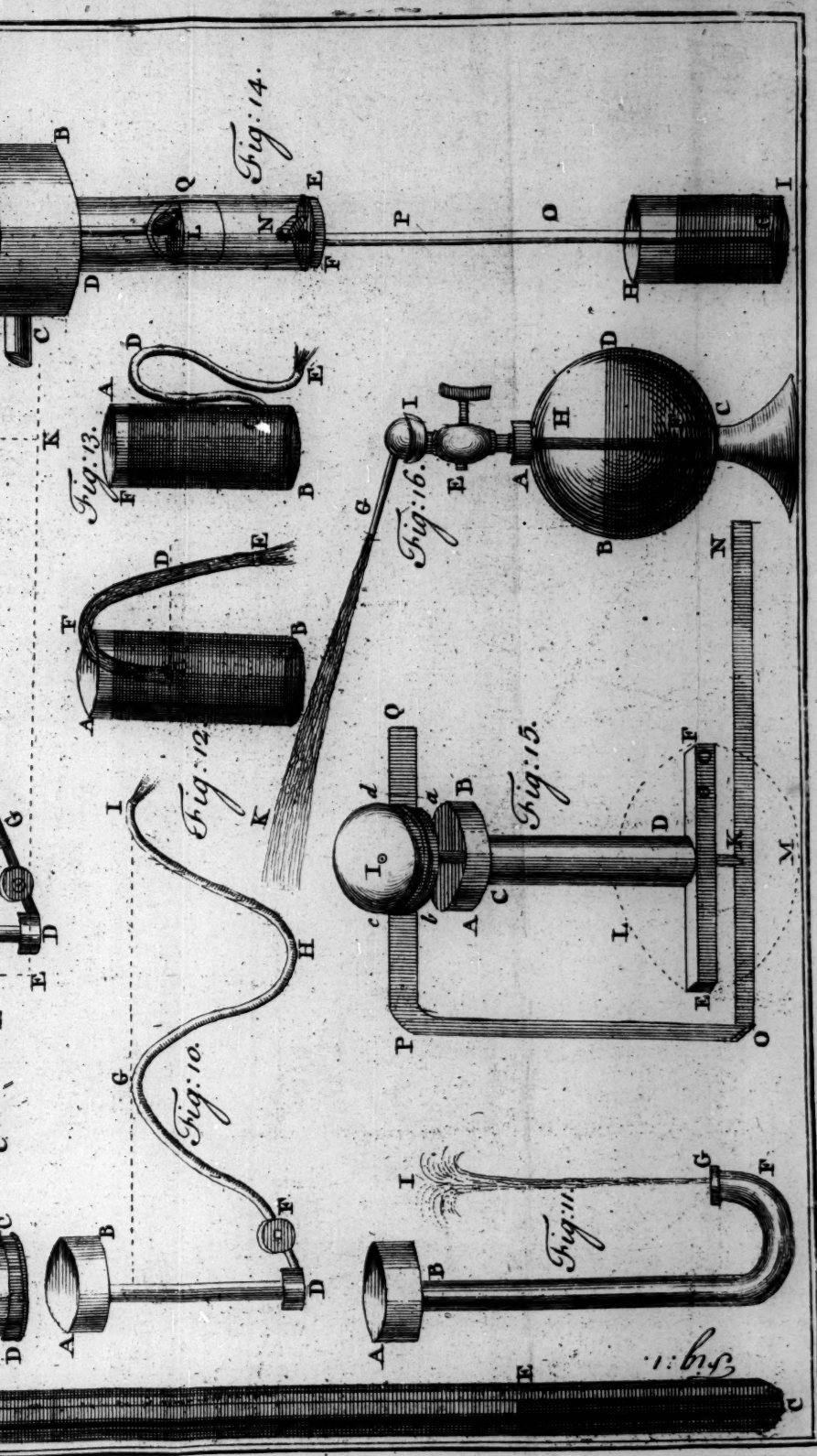


Plate VI.

Fig. 1.

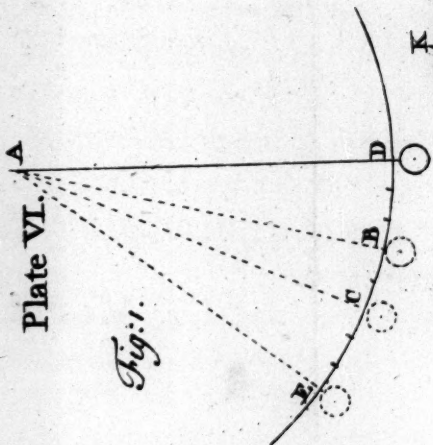


Fig. 2.



Fig. 3.



Fig. 4.

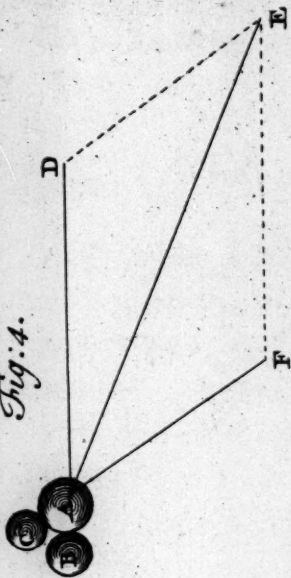


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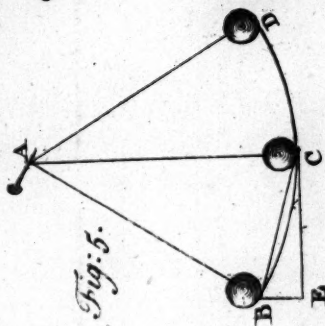


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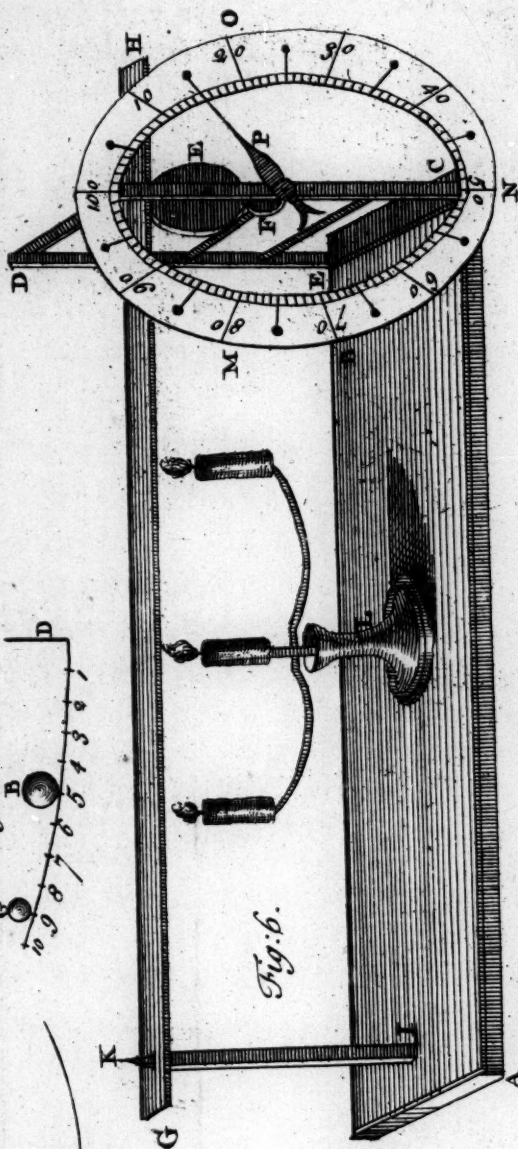


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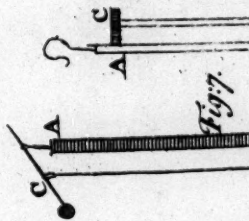


Fig. 8.



Fig. 9.



Fig. 10.



Fig. 11.



Fig. 12.

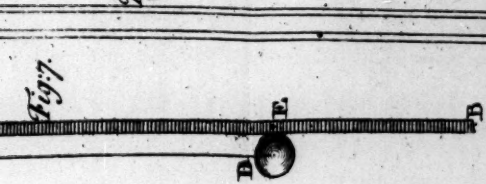


Fig. 7.



Fig. 8.



Fig. 9.

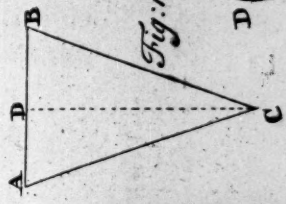


Fig. 10.

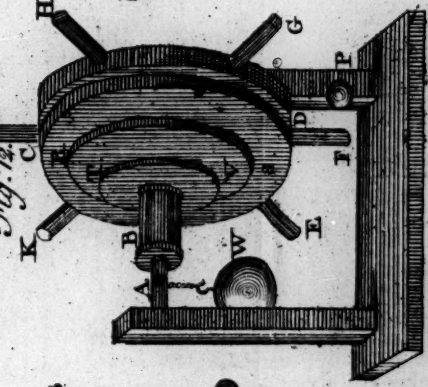


Fig. 11.



Fig. 12.

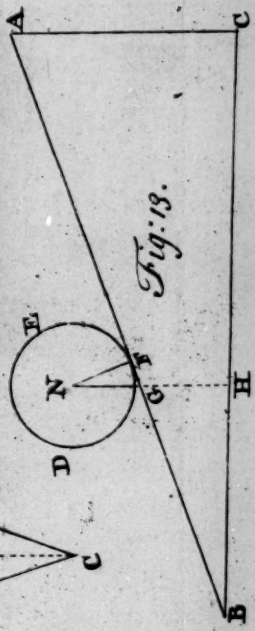


Fig. 13.

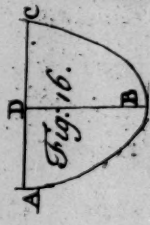


Fig. 14.



Fig. 15.



Fig. 16.

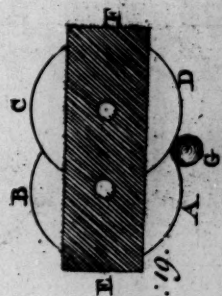


Fig. 17.



Fig. 18.

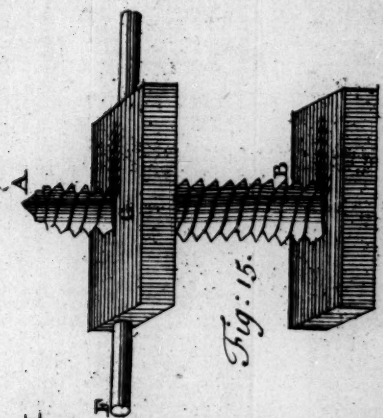


Fig. 19.